A

PRACTICAL MANUAL

FOR THE

ENGINEER, ARCHITECT,

AND

OVERSEER.

ARRANGED AND COMPILED

BY ORDER OF THE HONORABLE THE COURT OF DIRECTORS AND
THE GOVERNMENT OF INDIA,

BY

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PART I.

SELECTION AND PREPARATION

OF

MATERIALS.

PREFACE.

HAVING received the permission of the Hon'ble the Court of Directors and the Government of India to prepare a complete Manual of the several Arts and Sciences in the practice of Engineering and Architecture which are applicable to Public Works in India, I have availed myself of every source within my reach from which to draw such useful material as might advantageously be engrafted on to the result of 28 years' experience in the Department of Public Works in the Bengal Presidency, and two years' research in the Workshops of Birmingham and Manchester ; nor have I failed to press into the service many useful memoranda culled from the valuable MSS. unpublished matter, and "proceedings" of the Institution of Civil Engineers in London, of which I am a Member.

The brief period of one life is totally inadequate to the embodiment from personal observation, of knowledge in a Science so varied, so extensive, and composed of such numerous branches, that each subdivision is sufficient to engage the attention and practice of a distinct set of men. I have therefore been the more diligent in referring to authors whose works are records of their successful practice, and the result of whose labors have stood the test of Time and public opinion. Such are those, both written and constructed, of Telford, Tredgold, Stephenson, Rennie, Tierney Clarke, Barlow, Vignoles, Cresy, Vicat, Totten and Millington, on Engineering subjects; whilst many practical details connected with Architecture and the Art of Building, have been adapted from Chambers, Stuart, Pugin, Gwilt, Nicolson, Leeds, Barry and Durand; nor have the Rudimentary Treatises lately published by Mr. Weale, been overlooked; the subjects in which have been written by the leading talent of the day, but they are so complete in themselves, so cheap, so portable, and thus so easily within the means and reach of all, that I have but partially referred to them, and only when any modern subject required the particular authority of either writer or practitioner.

The aim of this work has more particularly been to adapt the splendid results of the present advanced state of professional attainment to the practical purposes of the Department of Public Works in India; and in attempting this, there has not been neglected the faithful delineation of noble works actually constructed, and authentic detail of material at present successfully applied and in high repute; not only as a proof of the vast improvements going on, but as a stimulus to the production of similar undertakings, and guarantee of equally important issue. Thus may the road be opened to the yet hidden resources of this country, rich in all the crude material that the Engineer or Architect can desire, and lead him to raise the most elaborate works with confidence and security.

In a work like this, compiled with a view to its utility in the different localities comprising the Department of Public Works in India, it would be useless to attempt to lay down either the wages of workpeople or prices of material, which must vary in every division, having reference to peculiarly local circumstances; but numbers of laborers and quantities of material, which from experience are known to be required for the execution of a certain amount of work, must be alike for a similar amount of the same kind of work anywhere.

These numbers and quantities therefore will be given for all sorts of works, from which each officer can easily frame his rates and obtain correct values.

The work is intended to be divided into four parts, *viz.*

Part I.—The duties and acquirements of Engineers, Architects and their subordinates.—The choice, preparation and use of the several materials for building purposes.—Strength and stress of materials.

Part II.—Details of construction of all branches of Engineering and Building, including Embankments, and the improvement of Rivers.—Masonry in Stone and Brick.—Bridges of Iron, Timber and Masonry.—Roofs of Iron, Timber and Masonry.—Artificial Foundations.—Roads.—Canals.—Docks.—Drainage.

Part III.—Rudimentary Architecture.—Principles of Design as applicable to Public Buildings in India.—Specification.—Contracts.

Part IV.—Problems and Diagrams connected with course of study for Overseers.—Tables of specific gravity.—Weights of Iron and other Metals.—Scantlings of Timbers.—Practical Rules and Receipts.—Data for Rates.

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PRELIMINARY ESSAY

ON THE

ELEMENTS

OF

CIVIL ENGINEERING.

1. THE MOTTO that "Experience is the only true guide to Philosophy"* has led to the conviction that Theory and Practice must go hand in hand; brilliant however as Theory may be as far as abstract science is concerned, yet if the sources from which it flows are not in strict accordance with what is known to take place in practice, such Theory must be abandoned, and make room for that only which is so founded as to agree with the results of experience. Too many facts cannot be collected, and too much research cannot be undertaken to test Theory, which, when found to confirm the observations deduced from Practice, affords the surest guarantee of confidence.

2. In Europe the line of demarkation is drawn between the professions of the Civil Engineer and Architect, and both are more particularly employed in the strict line of their professional labours, through the subordinate assistance derived from clerks of the works, who are confidential aids in keeping the accounts and overlooking workmen, and also by the intervention of a variety of

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* Lord Bacon.

contractors of skill and ability, each performing a part in the construction, to which the attention of his practice has been exclusively devoted, and thus producing a perfect whole. In India, however, the case is very different, for with exception to the presidency, there are no practising builders, or masters of trades with knowledge, experience and capital to undertake a contract for any other than earth-work, and the patience and time of the engineer are even here severely taxed to obtain the proper performance of the work, to the hindrance of other duties—neither are there by trade wholesale brick-makers, house carpenters, iron-mongers or machinists, to furnish by order the requisite material and appliances for the Engineer's use; and although in all parts of the world an Engineer should be acquainted with the several trades, in order that he may successfully direct his contractors and workmen, it is more particularly necessary in India that he thoroughly understand the interior details of all workshops, and have accurate knowledge of the methods of selecting, preparing and using every kind of material, whether the produce of the quarry, the forest or the forge, for his professional excellence will depend on the correct adaptation of material, habits of discrimination and judicious superintendence. The Engineer in India is often liable to be thrown into situations, where from the ignorance of workmen, absence of mechanical means or other causes, he is entirely thrown on his own resources, and must trust to his ingenuity and knowledge to procure and fashion his material and to carry his work to a successful issue.

3. In India the Civil Engineer is also a Military Engineer, and though some of their operations are similar, they are carried on under very different circumstances. The Military Engineer is called on in time of war to reconnoitre or survey a road, to render such road practicable for the Army's march, to construct a temporary bridge, and throw up earth-works of various kinds, and these works from the haste in which they are executed, and the scanty means often afforded for their execution, are not calculated to endure, and yet they must be strong enough to answer the intended purpose. These works too he carries on in the face of enemies who are endeavouring to obstruct him in every way. In time of peace he is called on to exercise his talents in the construction and repair of fortifications and the various details connected with this branch of his profession; so that whilst exercising his calling as a Civil Engineer, he must keep up his habits of a Field Engineer's life, his energy, activity, and Military

skill must not be allowed to desert him, as his transition from the one to the other employment is sudden. Thus the talents of an Indian Engineer are required to be as manifold as his services are arduous and valuable.

4. The Civil Engineer's duties are carried on in a manner very dissimilar to those of the Military, his surveys are without danger, he has time to consider his plans, facilities for obtaining his material, his works are not those of a day, destroyed as soon as finished, his aim should be to work for posterity, and to make his work as enduring as possible. To do this, every aid of science must be called into requisition, he must be acquainted with the various materials he has to deal with, their mechanical properties of cohesion and solidity, and their chemical properties which make them more or less liable to decay. He must understand the powers of mechanics to raise vast masses to great heights, also the laws of forces by which bodies press and operate upon each other, and the best means of putting parts together with a view to the framing of a roof, whether of iron or timber, or the construction of an arch, and these can only be ascertained by mathematics. The power of the elements in every shape has to be battled against, the merciless wave, the rapid torrent, the gigantic power of steam, the raging tempest, have to be withstood and overcome by constructions which shall resist them all, and though it is seldom in Europe that one attends to all, yet the Indian Engineer's occupations display a versatility which should be capable of coping with the numerous branches of his profession, nor are the above items all that such profession embraces, he should be an Architect as well as an Engineer, and a study of the guiding rules and principles of this ennobling science must be entered into ere he undertake the designing or executing of public buildings of extent and consequence.* It is a fallacy to suppose that all that is necessary to form an Architect is, that he be able to draw tasteful designs and elegant compositions gratifying to the eye, and that he be capable of embellishing the position of its erection; he is totally unworthy of the name, unless he be able to carry the whole detail into execution, from the selection of the clay which forms his bricks, to the completion of the most lofty moulding. The very derivation of the word αρχος τεκτων implies this power, and without the conception of the means of execution, he might

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* A Treatise on Architecture is intended to be given in this work, forming Part III.

produce designs apparently admirable on paper, but impossible to be carried into effect. On the contrary, possessed of the principles, he works boldly, obtaining a maximum of stability with a minimum of material, combining the taste of the Architect with the strength of the Engineer. He should therefore not only be able to design with artistic and practical exactness, but be able to execute the artificial foundation of piling, concreting, building, roofing, and completely finishing the entire structure.

5. It is hence apparent that a very considerable acquirement of knowledge of various kinds is necessary to the practical Engineer and Architect, and great assiduity and application are required for the attainment of most of that knowledge: much too that is obligatory from the officer or head, is to be expected from the subordinates of the department, the Sub-Assistant Engineers, Overseers and Assistant Overseers, before they can be considered qualified to act as aids to the Engineer or Architect, so as to be entrusted with the execution of public works, as incalculable mischief has been and will be caused from the absence of the knowledge of the arts of building in its various details, the employment of improper or inferior material, the insecurity of the framing of a roof to bear the superimposed weight, or an unscientific Bridge. They should know—

Arithmetic, Vulgar and Decimal Fractions, Geometry,	As the foundation of all the following.
Algebra and its application to Geometry, Plane Trigonometry, Mensuration,	As applicable to Surveying, Levelling, Estimating, Earth-work, Road-making and Architecture.
Preparation and use of Materials,	Stone, Brick, Mortar, Timber and Iron.
The laws of the Mechanical powers, Strength and Stress of Material,	As applicable to Carpentry, Constructive Masonry, Iron-work and Architecture.
Artificial Foundations.	
Earth-work,	Of Road-making and Embankments, Drainage, Canals, &c.

Levelling and taking Sections.
Constructive Masonry.
Principles of Carpentry.
Ditto of Bridge-building.
System of Accounts and Book-keeping.
Estimating and Measuring.
Outlines of Architecture.

As is the case at the College at Roorkhee, apportioning to each grade that amount of study both theoretical and practical, which shall most effectually fit them for their appointed duties. The contemplated increase to the College at Roorkhee, with the addition of its museum, library and model-room, is calculated to confer a most important boon on the Department of Public Works, by sending out valuable and practical assistants to the Engineer, the effects of which can be foreseen by all who have had the experience of former years in the Department. This extension of the College must eventually be highly appreciated by Government. The different classes of study at the College will be given in Part IV. A student having gone through the above course, could not be more usefully employed, or gain a better insight into his duties than by commencing his career as a clerk of the works, and there are no means that could be adopted better calculated to improve the condition of the Public Works, or the position of the Engineer, than that of providing each officer with such assistance, relieving him from the fetters of books of accounts which tie him to the desk, leaving him insufficient liberty for the superintendence of his district work, and none at all for the improvement of his mind in the various branches of scientific attainment which have been proved to be necessary to the Indian practical man. Whilst relieved from the accountant's work, the Executive Engineer would find leisure to superintend one or two apprentices, who, by studying in his office and attending his works, may be gradually trained to be Overseers, but who should not be allowed to practice or receive their pay as such, till proficient in the studies laid down for this grade at Roorkhee, of which the Engineer will satisfy himself particularly.

6. The duty of a clerk of the works is to give no directions of his own, except in cases of emergency, in the absence of his superior where delay would be attended with pernicious results, but to act under the orders and specifications

of his principal, and to watch that such are punctually complied with. He should constantly visit the works of the station at which he is resident for the above purpose, mustering work people as often as possible, and taking account of materials, their quality and consumption. He should measure the works as they proceed, and be careful that they correspond with the working drawings, of which he should have the custody. In the office he should be entrusted with the keeping or checking of the day books, the examination of estimates after they have been prepared by the superior, and the rough drafting of bills. He thus not only becomes of essential service to his principal, but constantly surrounded by work and workmen; he sees operations going on, and becomes acquainted with both means and tools, is readily able to calculate the quantity of work which a certain number of workmen should perform in a given time, and lays up for himself a fund of useful knowledge which cannot fail to be useful to him as a future Civil Engineer.

7. One of the preliminary operations of an Engineer or Architect is the preparation of the drawings for the execution of the works that are to be carried into effect; neither reading or study will of themselves enable him to digest a good plan, experience and patience must be brought to his aid. Its primary formation is an effort of the mind, and the first step is to gain an accurate acquaintance with the locality of the work projected; this must be obtained by a visit to the spot, and by making the necessary inquiries of those living in the vicinity, who are best able to supply the desired information, as for example if a Bridge is to be built, the particulars of the stream should be ascertained, depths at different seasons, height of violent floods, soil of banks and bed, fall of bed; facility that exists for procuring the necessary materials, whether stone, brick clay or lime, means of transportation, kind of workmen, with all that may be desirable to aid in the formation of correct plans, and furnishing a specification and estimate in accordance therewith. In making these examinations the Engineer should never be without his memorandum book, noting down all that occurs, or comes under observation, without trusting to memory; such notes, if persevered in, with corresponding sketches, will form a useful stock of practical knowledge for the future. Having arranged the plan of what he intends to do in his mind, the next step is to render it intelligible to others, viz., those who have to canvas its merits or defects, those

who are interested that the projected work or building is adapted to its purpose, and those who have to carry it into execution. The rendering the design palpable to others can only be done by means of a written specification in conjunction with the drawings, the former embracing such particulars and detail as a drawing cannot show, viz., the nature of the material, the proposed way of working it, the details of the construction, and such other matter as would be perplexing if it were shewn on the plan. The specification is intended to leave nothing optional either to an overseer, a contractor or workman of any kind, and to prevent any ambiguity or misunderstanding on the part of the unprofessional authority who is to occupy the building, or the authority who has to sanction the undertaking, and who, unable to visit the spot, trusts solely to the specification to render intelligible the drawings. The Engineer himself will be a gainer by a concise specification as well as a detailed set of drawings, for by rendering his intentions clearly understood, after-thoughts are avoided, whilst alterations and additions and contingent bills, which add so much drudgery to all offices concerned, are dispensed with.*

8. The drawings proper which every Engineer should execute are—

1st.—A ground-plan or horizontal appearance of every part of the building, as seen from above.

2nd.—A longitudinal elevation, which is the external appearance the building will present, viewed geometrically with the longest dimensions towards the eye.

3rd.—An elevation of one of the short sides, if the building be considerable.

4th.—A longitudinal section, or the appearance of the building if it was cut through in the direction of a certain line, which should be referred to on the ground-plan.

5th.—A transverse section, or the same in an opposite direction.

6th.—Details on a larger scale of the principal parts should be given, such as construction of roof, artificial foundations, mouldings, and a block-plan of position, shewing drainage, &c. Every detail must be given with faithful accuracy as to actual magnitude and relative geometrical proportion, and a correct scale drawn on some convenient part of the paper.

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* A model specification will be given in the course of the work and appended to Part IV.

9. To enter into the details of the various elementary branches of study which have been enumerated at para. 5, is not the object in this work, nothing has been laid down but what every Engineer should know, and having directed him in the course to be pursued, he will find all the primative detail necessary to prepare him for the practical and constructive duties of his profession, as applicable to the Department of Public Works in India, set forth in the following Chapters.

PART I.

CHAPTER I.

STONE.

10. Mineralogists and Geologists enumerate a great variety of stones, but the Architect and Engineer recognize but three great divisions, known as "Free Stone, Slab Stone, and Rubble Stone," so called from their hardness, and the appearance of their natural fracture. Of these there are many varieties.

11. Free Stone is always granular in its texture, though the grains vary in magnitude, and occasionally are chrystalline in form. The name of this stone is derived from the freedom with which it is worked, one of its leading characteristics is, that though durable against weather, it is yet soft enough to be sawn by the stone-worker's saw, or cut into form by the mallet and chisel. It is therefore particularly valuable for decorative purposes, such as columns and their capitals, cornice, frieze and mouldings, or for the building of walls where external surfaces are desired handsome.

12. Marble in all its varieties ranks first amongst free stones, on account of the large masses in which it is found, its durability, its non-absorption of water, the ease with which it is worked, and high polish it takes. It is one of the primitive limestones, being a carbonate of lime, and when pure, is perfectly white, though rarely found unvariegated.

13. Alabaster is a white stone much resembling statuary marble, but is a sulphate instead of a carbonate of lime, therefore not a marble; it is easily

[illegible] being brittle and not durable in the open air, is used chiefly for [illegible]tal purposes. Marbles in general have no other names except [illegible]d from the places where they are found, such as the Parian [illegible]e from the Island of Paros, of the very finest of which the [illegible] were formed. Florentine marble, a reddish-brown, from [illegible]ck and gold, from Italy. Breccia, consisting of angular fragments of different colored marbles cemented together. Sienna marble, of a rich buff color, variegated by other colored streaks. Verd Antique, that splendid green marble presenting almost every shade of brilliant green. It is called Egyptian marble by Architects, and Serpentine by Geologists. The common marble obtained in this country is impure, it is either streaked white, or what is called the Dove marble, these are easily worked, and impart a stability and great beauty to buildings.

14. Next to marble, in point of firmness of grain and durability is the fine white sand stone, which is that most frequently used. It is composed of a fine silicious sand held together by a peculiar natural cement, so fine that it cannot be perceived between the grains. It bears fine carving, is strong and durable, and not affected by the weather.

15. The Oolite, so called from its resemblance to the roe of a fish, is of a yellowish-white color, granular, and wholly calcareous, its grains varying from the fineness of sand to the size of peas, united by a natural cement quite visible to the eye; the fine grained alone is fit for building with, it is very soft at first, and may be cut with a common hand-saw, but hardens from exposure.

16. The ferruginous or red sand stone, common in Central and Upper India, consists of a coarse silicious sand cemented by an oxide of iron, this stone likewise acquires hardness by exposure to the air. Besides the purpose to which it is put, it is well adapted for Bridge building, especially in arches of large span.

17. Soap-stone is another variety of the soft free stones, found in India, it will stand great heat, and is therefore applicable for fire places and chimney pieces, furnaces, &c., but is too soft for building with.

18. Granite ranks amongst the most hard and durable stones, it more properly belongs to the family of refractory, than that of the free stones. It bids defiance to the saw and almost to the chisel, but still it can be worked

with expense to any form, to a fair but not smooth face, and has no tendency to split. Its component parts are quartz, felspar and mica, closely [illegible] when the stone is fine.

19. Slab stone, is of a lamellar construction, which is of a [illegible] splits into parallel plates of greater or less thickness with ease, [illegible] great strength in the direction of its laminæ, and can be cut [illegible] the saw. This stone must always be used with its natural joints in a horizontal position, for otherwise the outsides will scale off and the stone fall to pieces. It is therefore useful for flooring and covering of roofs, paving and stairs, or in the foundations of extensive buildings, as being flat and affording equal pressure to a large surface of ground.

20. Rubble or rough stone, comprehends all those which from their hardness cannot be sawn, and from their brittleness and irregularity of grain resist all attempts to reduce them to regular shape, save by very expensive processes. Such are flint, trap formations, and compact lime stones; these stones are only used for rough work in foundations, or filling in walls of more than ordinary thickness, backing and strengthening them in parts not exposed to view.

21. The Engineer may be so situated in this country that he may require to quarry and raise his own stone, the following observations will therefore be useful. The stone found near the surface, which has been exposed to the atmosphere, is not so sound as that below, where it has been subjected to pressure, and where consequently it will be of greater density. On opening a quarry, the first consideration is how to raise and deliver the stone in the least expensive manner. The work should therefore not be begun too low, but an excavation made in the side of a hill, in preference to the top, that the road leading to and from it may be as gentle as possible. When necessity compels the after-delivery from below, a gentle descent should be cut to it to assist the draught of the animals employed if machinery be not available.

The stone is found in beds or masses, and on close inspection will be found subdivided by natural joints or fissures, at which places the stone has no natural adhesion, and one block will easily part from another, and this may be done without fracture to either if conducted with care, though the first block of all must be sacrificed by either blasting or hammer and steel wedges, in order to get out the contiguous blocks. The vertical fissures should first be sought for that correspond with those in front, and the size and position of the contiguous blocks will thus be exposed, leaving it for determination which shall be the one sacrificed to enable the adjoining ones to be got out. Steel wedges require to be worked with heavy hammers till enough of one stone be cut away, to permit the removal of the block required, which can then be shifted by small wedges under and on the undisturbed side of it, and when shifted can be easily removed by the application of iron crow-bars or levers raising it sufficiently to get rollers underneath, by which it can be transferred to a truck, which is a four-wheeled platform of more than ordinary strength, running either on a rail or hard-prepared surface.

22. When natural fissures do not exist or smaller blocks are required than those indicated by them, such fissures must be made artificially, by drilling a line of holes at regular short intervals in the direction required. A row of conical steel-pointed pins, rather larger than the holes, are set one in each hole, and struck sharply and simultaneously by Miner's hammers which will produce separation, but where the cleavage is easy, dry hard wooden pegs may be driven in, which if not successful from the blows, may be made to swell by forming a bank of clay round them capable of holding water, when the necessary effect will be produced if the wood was previously quite dry.

23. As levers are apt to break the sharp edges of stone fresh quarried, the assistance of an useful and ingenious instrument called a "Lewis," is brought into operation, being worked by a pair of blocks and fall, or system of pullies, the end being connected to a windlass or crab, and the upper block to a rough crane or beam fixed nearly perpendicularly, its upper end being over the stone and the crab at its foot. (Figure 1, Plate I.) shows the construction of the Lewis put together ; in the opposite direction the sides are parallel, and of the same thickness, from one and a half to three inches, according to the magnitude of the work. In front the pieces *c d*, *c d*, spread out so as to be twice as thick at the bottom *d d*, as they are at *e*, these thicknesses may be one and two inches. The middle piece is of the same size from top to bottom, two inches thick. When the three pieces are put together, the distance across from *c* to *c* will be four inches, and from *d* to *d* six inches, but on taking out the screw-pin, the central piece *e* may be withdrawn, and the outside pieces brought together, when the distance from *d* to *d* will be reduced to four inches, so that if a dovetailed

cavity is sunk in the middle of the upper side of a block of stone four inches wide at top and spreading to six inches at bottom, and deep enough to take in the whole Lewis (which may be from four to seven inches long), the two pieces can be separately introduced, and on putting the centre piece between them, with the bolt and shackle attached, no force can withdraw the instrument without tearing away the upper part of the dovetail. The Lewis therefore becomes a most powerful handle for lifting or lowering stone.

THE DURABILITY OF STONE AND BRICKS—AND THEIR RESISTANCE TO THE CRUSH.

24. As the following remarks apply equally to both the above materials, they are here placed between them. The object of inquiry is their durability and strength, and how these qualities may be affected by their position in a work, a knowledge of this will affect the selection as well as their application to the greatest advantage. The durability of material can only be known by trial and experience, from which general deductions may be made; it is impossible to lay down rules applicable to all cases, as it must be a knowledge gained from experience, which forms the surest guide. All that science can do is to select the proper materials and to try their cohesive force or strength by approved methods, recording the results faithfully, and describing such material that its identity may always be recognised. Being in possession of such observations, it will be for the practical Engineer to make experiments on the materials he has to work with, in order to determine whether they are worthy of more or less confidence than the examples cited.

25. The absolute strength of materials depends on their cohesion and tenacity, so that strength will be governed by the quantity that is exposed to action, or the area of surface acted on. It is however found in practice, that the power to resist compression increases more rapidly than the surfaces. Fracture can only take place when the power applied is so great as to overcome the cohesion of the particles composing the mass, they then give way laterally and are said to be "crushed," so when a cube of any material of a quarter of an inch square is subjected to pressure, having no external support to assist it, it will give way more readily than if it was surrounded by eight other cubes of the

same material closely cemented to it, of one piece with itself, held together by the same cohesive power, and forming a square surface of three-quarters of an inch instead of a quarter, for here the lateral spreading of the original cube is, in a measure, prevented.

26. The resistance of stone and brick to the crush, may be considered both with respect to the weight they are capable of sustaining with the upper surface exposed, or if placed between two surfaces horizontally, what weight they would carry without crushing. It very rarely occurs that weights are suspended at the extremeties of stones, on the contrary both stone and brick are almost always pressed between two parallel surfaces. If we consider the great thickness given by the ancients to the supports of their edifices, we may suppose that they had but little idea of the resistance of the material they used; but the boldness of the architects of the middle ages who often carried immense masses on slender and lofty columns, leads us to the belief that they both studied and knew the strength and properties of stone in this respect, yet we have no trace of their research, their examples alone remain, a few of which are here given.

27. As an example of the smallest surface of the points of support of gothic architecture may be cited the two columns of the Church of Toussaints at Angiers, the diameters of which are 12 inches, their height 25 feet, they support pointed arches of free stone, and the weight borne by each is 35 tons. From the work of Monsieur Rondelet, whose results agree with the experiments of Gauthey and those of Mr. G. Rennie,[*] the following are taken as indications of the pressure exercised, in some of the boldest edifices, on a surface of nine square inches, given in avoirdupois pounds.

	Pounds Avoirdupois.
Piers of the Dome of Saint Peter's at Rome,	1022
Piers of the Dome of Saint Paul's at London,	1190
Piers of the Dome of the Invalides Paris,	922
Piers of the Dome of Saint Genevieve,	1840

The pillars of the Church of Saint Genevieve, support on an area of 9 square inches 1792 lbs., and the weight under which two cubic inches of the stone composing them crushed was 15,344 lbs. The pressure therefore supported by the stone of Saint Genevieve, is from eight to nine times less than that required to crush it. In the pier of the Chapter House at Elgin, the stone supports a weight of 5½ tons on each nine square inches, this stone is red grit, and has resisted this pressure for several centuries; the power of resistance appears to range between 12,720 and 23,925 lbs. on nine square inches of varieties of stone, whilst that of brick averages 9,150 lbs. on the same surface. As a general rule, neither material should be allowed to carry more than ⅑th of the weight that has crushed them in small experimental cubes,* and in the voussoirs of an arch even this would be too much, unless under the assurance that the pressure is equally spread over the whole surface of the joints.

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[*] *Philosophical Magazine*, Vol. LIII., page 172.

28. The following are the results of experiments on stone and brick conducted by Mr. George Rennie.—

	Pounds Avoirdupois.
A cubic inch of chalk crushed with,	500
An inch and a half cube of half burnt brick,	1065
„ Ditto „ well burnt brick,	1617
„ Ditto „ hard paving brick,	2254
„ Ditto „ Red sand stone,	7070
„ Ditto „ Portland white sand stone,	10284
„ Ditto „ Yorkshire slab stone,	12856
„ Ditto „ Statuary marble,	13632
„ Ditto „ Granite,	14302
„ Ditto „ Compact lime stone,	17354

Density as expressed by specific gravity does not influence the duration of stones or rather their resistance to fracture; for statuary marble that has a specific gravity of about 2·760 has not so great a power of resistance as granite, the specific gravity of which is 2·625.

29. The rule that is generally followed for determining the necessary strength and dimensions of a column for vertical support is to take such of the experiments as have been detailed as may suit the case, and multiply the result given till it reach the power sought for, and then only to take one-fourth or fifth to work upon. Thus if a square inch of brick can safely bear 600 lbs.,

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* One-ninth of the crushing weight is about equal to one-fifth of what may be termed the power of resistance, or what the material can bear, although it would not be prudent to subject it to so much.

two inches should support 1,200 lbs. and ten square inches 6,000 lbs., but instead of trusting ten inches of brick to bear 6,000 lbs., but a fourth or fifth should be placed on it, or, if the whole load is necessary to be carried, the surface of the brick-work should be extended to four or five times 10 square inches; this is merely making the strength increase as the area, and then using one-fourth of the result, (para. 27) and such is deemed safe to guard against what may be termed imperfect construction, by which is meant the almost impossibility in practice of getting either wood or stone in large pieces to bear equally on every part of the surface prepared for their support. Thus a pier of brick-work containing 180 square inches of surface might be built to support a weight which it would be fully competent to bear, if distributed equally over its surface. But in placing the load on it, either from difficulty of raising or other cause, it might happen to rest on only 10 or 20 square inches, which being incompetent to bear it, would give way, transferring the weight to some other small portion, equally weak, and thus the whole might fail.

The specific gravity of ordinary sand stone is 2·113, weight of a cubic foot 141 lbs., is crushed on an average by 5,923 lbs. on square inch.

CHAPTER II.

BRICKS.

30. There are four distinct points for consideration in the manufacture of this material; 1st, the preparation of the earth; 2nd, the moulding; 3rd, the drying; 4th, the burning.

THE PREPARATION OF THE EARTH.

31. Clay is the material that has at all times been used for making bricks, it will be useful therefore to notice in the first place its peculiar properties, in order to show the propriety or necessity of certain operations in the manufacture of the material called "Brick."

Alumina is one of the primitive earths, and constitutes the plastic principle or base of all kinds of clay and loams, it derives its name from alum being obtained in the greatest degree of purity from that substance,* while the varying properties which are found in clays arise from their admixture with silica, iron, lime, felspar, &c., which, combined in certain proportions, render the clays useful for various purposes and manufactures. The red bricks owe their color to the presence of a large proportion of oxide of iron.

32. Many clays are so mixed with gravel, that before it is fit to be moulded into bricks it should be subjected to the process of being passed between rollers (para. 53) and afterwards through the pugmill (para. 54), though

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* Pure alumina or alum deprived of its sulphuric acid and potash, is a white tasteless insoluble substance, attracts moisture and adheres closely to any moist surface, when mixed with water is ductile and tenacious, and capable of being moulded to any form, hence its value to the potter.—*O'Shaughnessy's Manual of Chemistry.*

if the former has done its work well and effectually crushed the gravel,* the pugmill need not be used except for the preparation of moulding, arch, and column bricks, and particularly for tile-making. The gravelly clay is generally of a yellow ochreish color, and the pebbles containing lime, would, if burnt with the clay, expand and split the bricks. Attention however is necessary in the use of this clay or "marl" containing lime, as but a very small proportion of that substance is admissible in brick clay, and then only in a pulverized state, the presence of lime can easily be tested by pouring a little acid on a solution of the clay, when, if it be present, an effervescence will be apparent. In alluvial soils bricks made of the upper earth are apt to crack in drying and warp in burning, however well tempered or mixed with other ingredients, such soil is therefore to be removed and better clay sought for below.

33. A stiff, tenacious, plastic clay is unfit for making into bricks, as they will certainly split and fall to pieces in burning, a milder clay or "loam" is the proper kind containing a certain quantity of sand, and when this loamy soil is not found naturally, it must be imitated by adding sand to render the clay less tenacious. The dark volcanic friable soil, and the disintegrated red soil of Bundelkhund and Malwa, are totally unfit for brick-making, as their component parts possess no self-adhesive qualities, and even in a kiln-burnt state they will not resist heavy rain but crumble under its effects, they are therefore out of the question in a sun-dried state. Beneath such soils the ochreous clay will often be found and should invariably be sought for where it is necessary to make bricks in those parts of the country.

The Dutch make a most extensive use of bricks, of which they have several kinds. Not only are bricks used for ordinary building purposes, and for furnaces, but also in great quantities for foot pavements, towing-paths, streets, and high roads. It may be observed, that they have of late been used very effectively in England for the pavement of railway stations. The paving bricks, or Dutch clinkers, are the hardest sort, and are principally manufactured at Moor, a small village about two miles from Gonda, in South Holland. The brick fields are on the banks of the river "Yssel," from which the chief material is derived, being no other than the slime deposited by the river on its shores, and at the bottom. The slime of the Haarleem Meer is extensively used for this purpose. This is collected in boats, by men with long poles, having a cutting circle of iron at the end, and a bag-net, with which they lug up the slime. The sand is also obtained by boatmen from the banks of the river "Maes." It is of a fine texture, and greyish color. The hard bricks are made with a mixture of this slime and sand. River sand is recognized as one of the best materials for bricks, and is used by the London brick-makers, who obtain it from the bottom of the Thames, near Woolwich, where it is raised into boats used for the purpose. For what are called in France, Flemish bricks, and which are manufactured in France, Flanders, and on the corresponding Belgian frontier, river sand is preferred, and is obliged to be obtained from the Scheldt. At Ghent, and lower down, a considerable traffic is carried on in the supply of this material. The quantity used there is about one cubic foot of sand per cubic yard.

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* Practice in Warwickshire, where the best bricks in England are made.

The slime and sand, being mixed, are well kneaded together with the feet, and particular attention is paid to this part of the process. The mixture is then deposited in heaps. The mode of moulding and drying is similar to that used elsewhere. The practice can be effectually applied in Calcutta, and wherever the rivers afford slime and sand similar to the above. I have seen excellent bricks made at Howrah from a mixture of river slime and brick clay.

34. To prepare clay for brick-making the invariable practice both in Europe and America is to dig it from its native bed previous to the setting in of Winter, in order that it may be subjected to the action of frost under the effect of which it disintegrates, and its substance divided into such minute particles as to render it more fit to be combined with other substances necessary to the manufacture of good bricks, such practice is strongly recommended to be followed in India, for the cold is sufficiently intense to act effectively on the clay; by far too little attention is paid to the manufacture of this most useful material, and the value and importance of following the firmly established practices herein described, will be fully acknowledged by the production of a material which shall resist the corroding influence of moisture so destructive to the bricks as at present made. The soil must be dug, and if not naturally fit for the purpose, ought to be artificially rendered so, by the following means, which is an abstract of the practice above alluded to. Quantities of clay each equal to

the manufacture of about 2,000 bricks or 260 cubic feet, are to be dug up before the cold weather, (September and October)* and laid on levelled ground, which if a little below the general surface is better, if sand is required, it is then added, if not, the clay is worked without, but in either case, it is subjected to a tempering process being cut, slashed, and well worked with spades or fowrahs, adding water to soften it. If the clay is gravelly as described in para. 32, it is to be passed between the rollers previous to being tempered. When the clay has been well worked for several days till no lumps are perceptible, it should be left till February, when the sun getting warmer the whole will have become an uniformly soft and yielding mass. This process should be considered necessary as well for sun-dried as for kiln-burnt bricks, and even for the clay plaster with which the former are almost always covered, to which a proportion of cow-dung should be added.

35. Although "cucha masonry" or masonry of sun-dried brick has been executed so as to last for centuries† by the Egyptians, Greeks and Romans, its duration was owing partly to the clay having been exceedingly well tempered, partly to its having been mixed with finely chopped straw or wood dust, and partly to the length of time the bricks were allowed to be exposed to drying before they were used. In India the practice is to dig, mould, and place the bricks in a wall often within two months, with but little regard to the nature of the clay, untempered, and not perfectly dry; in that state the bricks have the elements of decomposition and destruction within themselves, being very porous, full of impurities, and containing the larvæ of white-ants, the most destructive of all causes. Now the disunion of the particles of the clay by cold, the proper mixture of sand with tenacious clays, and the suffering to dry for an entire season or more, would tend materially to destroy the germ of white-ants in the bricks themselves. When small quantities of bricks are re-

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* It is generally known by the month of October, what work is likely to be undertaken during the following season, and the quantity of clay can be accordingly prepared, and sufficient bricks obtained to last till the succeeding year's kilns are burnt.

† One work in particular (a pyramid) 10 leagues from Cairo, 150 feet high, rectangular base 210 × 157 feet measured by Dr. Pocock's in 1738, constructed by the Egyptians. The Greeks and Romans likewise used them, but not until they had been dried for two years at least. At Utica the Magistrate was forced to certify that the unburnt bricks had been made five years before the inhabitants would use them.—*Cresy, Book* 11, *Chap. IV.*

quired the clay may be tempered and mixed by placing it on a hard bottom, well working with spade and fowrah and puddling or tramping it with the feet, the layers of clay never to exceed 10 or 11 inches in thickness, and as much water given as will sink the feet 8 or 9 inches at every step, layer after layer may be added till the requisite quantity is obtained, in this operation neither labor nor water must be spared, the water being afterwards drained off, or the clay spread out to dry.*

THE MOULDING.

36. Before the moulding commences, which it may in the latter end of February, the clay should be rendered perfectly mild and yieldingly consistent; if too dry, water should be added, if too moist it should be opened and spread, and during the hot weather it would prevent its return to lumps and otherwise getting injured if it were covered with light but firmly secured thatch, which as the clay is used would answer for drying all finer kinds of bricks and tiles under, a measure quite necessary with such material. It is at this stage of the process of preparing the clay that the London brick-maker adds the "breeze," which is the refuse of the dust-holes, and contains cinders, fire-dust, and decayed matter of kinds, and is added to the clay in the proportion of about $\frac{1}{6}$th, in order that the brick may possess an element of combustion within itself, and thus become red-hot throughout, the breeze besides materially improves its durability. Sawdust, cow-dung in powder, litter and dry grass of all kinds reduced very fine, would have a similar effect, and might with advantage be added to the brick clay in India, though about $\frac{1}{8}$th would be sufficient proportion for such ingredient, and the whole should be particularly well incorporated.

What is termed "strong clay," is generally sufficiently free from stones to be used without washing, and the bricks made from it are hard and sound, but are liable to crack and contract very considerably in drying, and become warped and mishapen in burning. These defects are in a great measure removed by mixing the earth with chalk, reduced to the consistency of cream, as will be presently described, which greatly diminishes the contraction of the clay, and improves the color of the brick.

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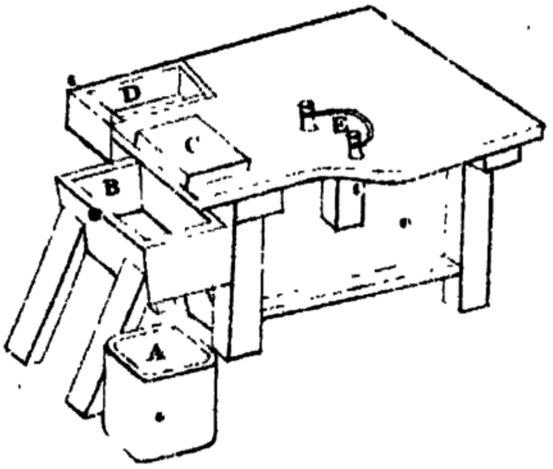
* Millington's Civil Engineering, Art. 484, page 267.

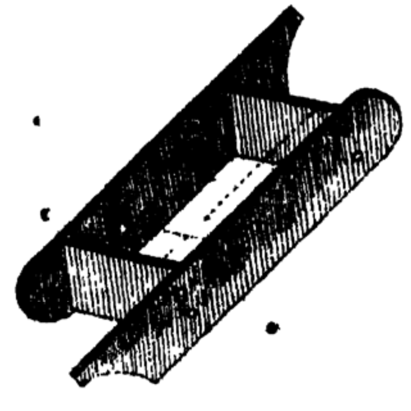
37. It is very necessary to see to the condition of the brick-moulds and tables, previous to commencing the manufacture of the season, and such inspection should not be entrusted to natives, who from their careless habits are unfit to appreciate the value of efficient means and will allow moulds to be used which have been somewhat distorted by wear, and tables with their surfaces uneven, split or warped. The moulds and tables should both be of hard-seasoned wood, the latter perfectly level, having a watertight trough conveniently attached for dipping the empty mould in to clean it after the delivery of each brick, or in which a second mould lies ready cleaned by an assistant boy, as the moulder is thus enabled to work uninterruptedly. The moulds should be of old seasoned teak, sissoo, or toon, bound and edged with thin iron plates and perfectly rectangular.

Isometrical view of a Moulding Table.



A, sand basket. *B*, detached water-box. *C*, moulding board. *D*, water-box. *E*, clay knife.

Isometrical view of Brick Mould.



For dimensions, see page 23 opposite. The edges are plated with iron.

As clay shrinks in drying, if the brick is to be 12″×6″×3″, the mould should be 12¾″×6½″×3¼″; but 11½″×6″×2½″ is a better dimension, as with the proper quantity of mortar, four courses of brick-work will measure a foot of height, which is a convenient reference; the moulds in this case should be 12¼″×6½″×2¾″. In Europe and America brick-work is measured by the rod, which is equal to 272¼ supl. feet, and in estimating, the walls are said to be one, one and a half, or two bricks thick, and as the number of bricks of the standard size in a rod of work of these various thicknesses is known, the total solid contents is easily arrived at. In India, as the practice has hitherto been invariably to calculate by the solid content, no counterbalancing good result would be obtained by altering the system; it may however be improved, if not perfected, and in addition to the reasons noticed above for laying down the measurement of the standard brick at 11½″×6″×2½″, the following may be adduced. Walls estimated at 2 feet and 1½ feet thick, are, if constructed of the brick 12″×6″, respectively 25 and 18½ inches in thickness unplastered ; and the native masons will often, if strict accuracy is enjoined, actually chip off the ends of good bricks that the thickness of the walls may gauge properly, and as they are not particularly careful in the operation, (in itself to be condemned) more is broken off than ought to be, the rough end is placed towards the interior of the wall, and the difference filled in with mortar, thereby weakening the wall, and wasting mortar. By the careful preparation of the material according to the instructions laid down, the mason is provided with bricks in the laying of which he has the least possible labor consistent with proper bond and plumb work, as there is no opening given to him either to mutilate the bricks or swerve from specified dimensions,* whilst the calculations of the architect are facilitated both as regards the measurement of executed work, and the quantity of material consumed. The size of the English brick 9″×4½″×2½″ has been justly condemned by Nicholson, Gwilt, and many modern architects and builders on account of the greater amount of labor, and quantity of mortar consumed than would be the case in the execution of a piece of work with bricks of somewhat larger dimension, though the above dimensions were fixed by law to enable the tax imposed to be equalized everywhere. The Act limiting the size of bricks was passed in the early part of the reign of George III.* when the advancement of the arts was a matter of far less importance than now, and may be considered rather an arbitrary Act than one resulting from due inquiry from experienced professional men, as its origin was owing to the limit of nine inches which the law assigned to a partition wall of a house. The ancient Greek bricks most in use were the Didoron or two palms in length, which corresponds to a foot, and they were half a foot wide.* There were also, the tetradoron and pentradoron, or three and five palms in length, but these were most likely used for pavements and slabs for roofs. As regards the burning, it is thickness, greater or less, which retards or facilitates the roasting, as the bricks are laid on edge in the kilns, with an interval between each row, and as 2½ inches the thickness of the smaller brick, is retained in the dimensions laid down for a standard, and moreover as the length and breadth respectively of 11½″ and 6″ have been shown to possess merits, the result is I think conclusive as to what is the best form of brick for building purposes. It is very necessary whilst the manufacture is in progress that half bricks be made in moulds for the purpose as good masonry cannot be executed without them. The loss by breaking whole bricks, and the insertion of irregular pieces in the interior of walls, are serious evils. To every lac of whole 15,000 half bricks should be made.

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* This matter will be more fully illustrated under the head "Brick Masonry."

38. Bricks may be and are by the Natives, moulded on the ground, but the surface should be first perfectly levelled and hardened, and also smooth plastered. An Overseer should constantly visit the brick ground to see that the clay is not put into the moulds in too moist a state, for the bricks will shrink too much in drying and be otherwise inferior, and yet this is an evil constantly committed, as it is easier to mould very wet clay. The consistency should be that of well-kneaded dough, let drop with some force into the mould, and pressed into the corners, the superfluous clay being cut off by an iron knife. Previous to commencing to mould, the table should be sprinkled with a fine silicious sand through a sieve, or what is better, the ashes of the kilns powdered and sifted, the moulds should be likewise sanded that the brick may turn out clean. A board ¾″ or 1″ inch thick, a little wider than the mould, and three inches longer, is laid over each brick as it is moulded, and the surface of the brick

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* Gwilt's Encyclopedia of Architecture, Book II., Chap. II.

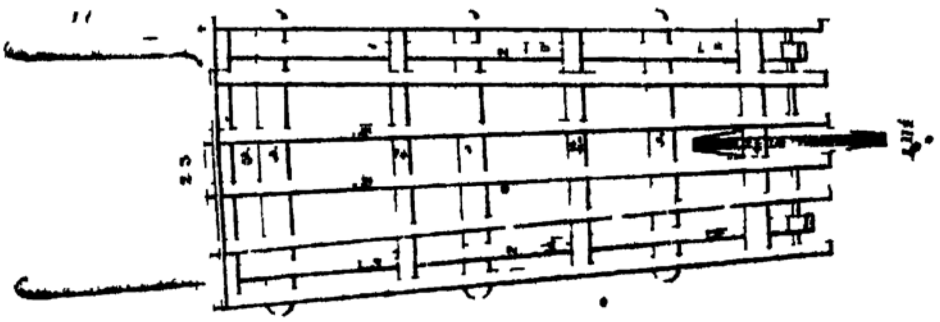
being sanded the whole is inverted, when the mould may be drawn up with both hands carefully, and the soft brick carried away to the drying ground on the board. The fresh mould is then taken from the water trough, sanded, and the operation continued. Two men and a boy are required to each moulder, one bildar for digging the clay, tempering, and supplying the moulder, and one for removing the bricks on the boards as moulded, the boy for cleaning moulds, supplying sand, &c. To prevent the loss of labor consequent on the conveyance of each moulded brick separately to the drying ground, a barrow should be provided with a raised stage on it, so arranged that it be level when the barrow is in motion, this stage should contain 20 bricks;

PLAN AND SECTION

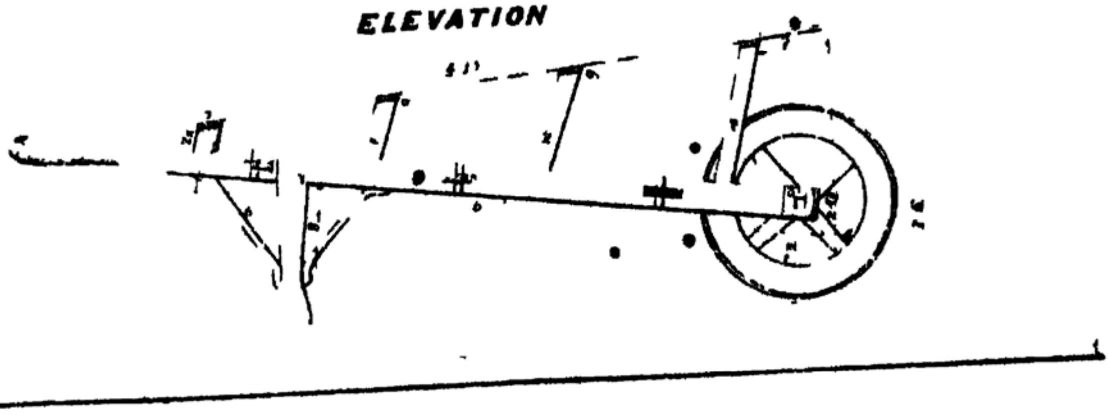
OF A

BRICKMAKER'S HACK BARROW.

PLAN



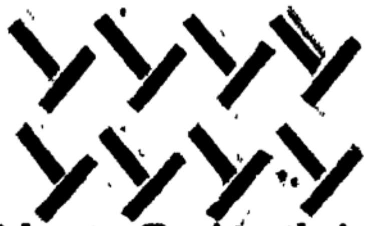
ELEVATION



care should be taken so to dispose the tables or moulding places with reference to the drying ground, that the barrows shall not have inequalities of surface to pass over as concussion will be injurious to the yet tender brick. The turning boards should be left under the bricks for half an hour after they are first deposited.

THE DRYING.

39. The surface of the drying ground is of course sanded over, and the man in attendance, as soon as the bricks have become a little hard, should move them to the sanded spot from whence they were first deposited, placing them on their edges, by inclining the board with one hand and applying the other to the brick, whilst he slides away the boards to be returned to the moulder. The soft bricks are disposed in an angular manner like a worm-fence, but in no case more than two inches apart and not touching any where thus— A row being finished, the bricks are sanded on their tops, and when sufficiently hard, a second tier may be laid on them, and soon till six tiers are completed, which is as much weight as the lower ones will bear, without affecting their shape. The object of thus placing them is to allow the wind to blow freely through and dry them effectually, but this should not take place too rapidly or they will crack with the great heat to which they are exposed in May and June. It is advisable therefore that the lines of bricks be covered with a rough thatch, sufficiently strong to prevent its destruction by storms or the strong hot winds. The moulding should likewise be conducted under thatched cover; and it will be found that the expense attendant on all these so necessary precautions, will not enhance the cost of the material so much, but that far greater proportional advantages will be gained by the superior quality of both the bricks and masonry. When sufficiently dry for turning, the bricks should be moved to an adjoining spot previously prepared, disposed on their edges, this time laid parallel, an inch apart, the edge that before was downward being now uppermost. In the courses, each brick is placed over the



Millington's Civil Engineering, Art. 482, page 266.

opening between the two below, and the six courses again completed. They do not require the sun now and may be under cover of thatch, the air will complete the drying, they may require turning twice and should by no means be carried to the kiln till thoroughly dry.

40. Bricks required for fine purposes, such as columns, mouldings, or arching, are dressed, (when about half dry, so as to be handled without indentation) by placing them on a dressing bench for the purpose, first patting their surfaces with a flat board, and then chamfering them for their intended purposes, with a knife, *vide* Plate I. Fig. 2. Column and arch bricks are made in moulds expressly for such works.

41. The brown color of common clay is derived from the oxide of iron, which, when burnt, causes the brick to be red, such a color, though almost universal, is nevertheless hot and glaring. Calcareous clay of an ochreous tinge or "malm" earth has been found in several places in England which produces a buff-colored brick, and which is an excellent color, agreeable to the eye and cooling to the temperature of the building, such clay requires no mixture of sand, only ashes; where this clay is not found, the English brick-maker rubs the ordinary "marl" about in a peculiar kind of sand obtained in the River Thames near Blackwall, before dropping it into the moulds, and when moulded the bricks are laid on boards also covered with this sand, and the upper surfaces are sprinkled over with it from a sieve. Thus coated the bricks when burnt assume a greyish color, and are used for the facings of buildings.*

THE BURNING.

42. The term "burning" retained here on account of the usual acceptation of its meaning, is incorrect, the object being not to burn the clay, but to drive off the moisture by gentle and equally diffused heat, and then gradually to roast the bricks. This operation is one of great nicety, and various are the methods adopted for producing the proper degree of firing with the best effect, such are the kiln burning, clamp, flare oven, and as each may be applicable

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* It is well worth while for every person engaged in extensive district brick-making, to search and inquire for both the calcareous clay, and to analyze the sands of rivers, as the production of light-colored bricks is an object devoutly to be wished for in India.

with reference to localities and resources, it will be necessary to describe them all, pointing out their respective merits, and comparing them with the ordinary Hindoostani method which partakes of the nature of a clamp, and of which a description is given.

43. A kiln is formed of bricks cemented with clay built into a rectangular form, with very thick side walls, and a doorway at each end for carrying in and out the bricks, these doors are built up with unburnt bricks laid in clay whilst the kiln is burning, and a temporary roof of any light material is placed over the kiln to protect the raw bricks from rain during the process of loading, but which is removed previous to firing. The walls are generally about 3 feet thick at base, diminishing to 1 or 1½ feet at top, and may be strengthened by buttresses 2 feet wide, between the openings. The English kilns are generally 20 + 10 feet on the plan, and 12 feet high, containing 20,000 bricks, the fuel being wood. They have no chimney, and are as often without flues as with them. (Fig 3, Plate I.)

44. The bottom of the kiln is laid in regular rows of two or three bricks wide, with an interval of two bricks between each, these rows extend the whole length of the kiln, and are built generally six courses high, (Plate I., Fig. 4.) This is permanent work in kilns that have flues or fire-places built in their floors, but have to be renewed every time of loading when the kiln has a flat bottom. The openings between the walls are first laid with dry light wood, or shavings, easily kindled; then with larger brush-wood cut into short lengths to pack compactly, and lastly with strong burning wood. When this is done, the formation of the arches is commenced by the process of overspanning, each course of bricks extending an inch and a half beyond the course below, for five courses in height, taking care to back up well the overspanning bricks as the work proceeds, on both sides of the arch; great care is necessary in forming and closing the arch, for if it falls in during the burning, the fire may be extinguished, and many bricks broken. The intermediate spaces between the arches are next filled up bringing the whole to a level, and the loading then continues till the kiln attains its full height. In the loading or "setting" not only in the body, but also in the walls between the arches, the ends of the bricks touch each other, but narrow spaces must be left between their sides for the fire to play through. This is done by placing the bricks on

their edges, following the rule of "three upon three" reversing the direction of each course (Plate I. fig. 5). The kiln being filled, the top course is laid with flat bricks so disposed that one covers part of three others like a plait.

45. The kiln being finished, the roasting succeeds, which is a delicate operation, and should be attended to only by practised hands: the overseer should study this part of the operation of brick-making, for close attention and no little skill and care are requisite. The fuel is kindled under the arches, but must be closely watched, for being in a large body it would burn violently and crack the lower tiers. To check the burning, the arch holes are closed with dry bricks or even smeared with wet clay, to prevent the entrance of air, and the consequences of too rapid combustion. The fire should be made to smother rather than burn, that by gentle heat, the moisture remaining in the bricks, may be driven off, and at first they may be dried rather than burnt. This slow fire requires to be kept up for about three days and nights by occasionally opening the vents to supply air or fuel as either may be wanted, closing them wholly or partially till the fire has found its way through all the openings between the bricks, and begins to heat those at the top. To ascertain the progress of the fire the top of the kiln must be watched, and as soon as the smoke changes from a light to a darker color, the drying is complete, and the fire may be urged. The first vapour is light-colored, being only steam of the water evaporating, after that the real smoke of the fuel ascends, and the vents may then be opened to admit full draught, and a fire kept up from forty-eight to sixty hours, but not so strong as to vitrify the bricks, and wherever it encreases too rapidly the vents must be partially closed. Experience will show how much each particular clay shrinks in burning, the stronger the clay of the bricks the more the kiln will sink, and it is by this sinking that it is known when the contents are sufficiently roasted, about nine inches is the average, and when it is ascertained that the combustion is complete, all air holes must be stopped carefully with bricks and clay, and in this state it remains till cool, when the bricks may be distributed for use.

46. It is evident from the above process, that bricks of various qualities will be produced from the same kiln, for the fire being applied below, those in the vicinity will be burnt to greater hardness, perhaps vitrified, those in the middle well and equally roasted, whilst those at and near the top will be merely

baked or be "peela" as the natives call them, but they will often fetch a good price in the bazars, and serve to reduce the cost of the useful bricks.

47. In a little pamphlet lately issued from the Civil Engineering College at Roorkee, is a description of a kiln which is said to possess superior qualities to the above, as deduced from the experience of that institution, and as it has been successfully worked in Scinde* and is in common use in Persia, its more general adoption may be profitable.—(Plate 1, figs. 6, 7 and 8) show its construction. The interior dimensions are 31 feet 6 inches by 11 feet, and 6 feet 6 inches above the flues. In the interior of the kiln are parallel walls from end to end 6 inches apart, and 4 to 5 feet high. Three lines of arched openings in these walls form the flues from side to side of the kiln, open on one side for the supply of fuel, and at the other having small draught openings. The floor is sunk three feet below the level of the ground, and access to the mouths of the flues given by sloping away the ground on that side, down to the level of the floor. The whole interior of the kiln above the parallel walls is filled with bricks, at first with small intervals, and above packed close. It has no covering at top, save a temporary one during the process of loading. A vigorous fire is kept up for forty-eight hours by continued supply of fuel. The loss in this kind of kiln, by breakage, vitrifaction or under-burnt bricks is less than in the others, a proportion of 82 per cent. on an average being yielded of well-burnt serviceable bricks. A kiln of the above dimensions will contain 15,500 bricks 12″ × 6″ × 3″. The average consumption of wood is stated to be 575 maunds of dhâk or 20½ tons. A large proportion, but which would be lessened if a better description were used, as the dhâk (*Butea frondosa*) is not a good burning wood. The fuel in use by the Persians and which would improve the burning if applied where procurable, is what the natives put into the common Hindoostanee kiln, viz., stable litter, market sweepings, and all kinds of small combustible offal. Firing this kiln during high winds is objectionable, as the windward bricks will be under-burnt.

48. In clamp burning, the piling and disposition of the bricks is the same as described for the kilns, except that the lower arches are smaller, as they are only to contain brushwood or shavings to produce the first kindling. No fuel

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* By Captain Weller, Engineers. *See also* Transactions of Scottish Society of Arts, Vol. II., page 189.

of a large kind is used, but light litter, sweepings and small shavings are sprinkled over each course near the bottom, every second course about the centre and every third near the top. The first layers are an inch and a half in thickness, diminishing in quantity as they ascend, where the greatest action of the heat is. The vertical and horizontal interstices all become filled with light fuel, and the fire spreading as it rises soon converts the whole into one burning mass. The heat is thus generally distributed, and in order to confine it, the outside of the clamp is thickly plastered over with wet clay and sand, the bottom holes being shut or opened as occasion may require to regulate the draught.

49. Clamps may likewise be formed by arranging the bricks in a second set of flues or arches six courses above the lower ones, crossing them at right angles, continuing this process in both directions to the top, or height of 36 courses. Though the distribution of the heat is more equal in clamps, yet the outside bricks must receive but little advantage from the fire, but they will always serve for the casing of the next clamp, when by turning their unbaked sides inwards most of them will attain a degree of roasting as to render them marketable if not fit for other purposes.

50. The common Hindoostanee clamp of Upper India is somewhat in the form of a huge bellows or sector of a circle; (Plate 1, fig. 9) shows a Section, its rear width or length of the arch, varying from 100 to 150 feet. The mouth somewhat depressed below the ground level, and the clamp gradually rising to the rear. The mouth of this clamp is always placed to the westward, being the direction of prevailing winds during the burning season. The small Hindoostanee 6″ × 3″ × 1″ bricks should invariably be burnt with the large standard ones in this kiln, as by this means only will the latter be properly turned out; the proportion in a kiln of 150 ft. width of base and three tiers of height is 2,50,000 of the large to 10,00,000 of the small: four layers on edge of the large about an inch asunder, with two layers of the small, compose each tier, the lower tier of all being entirely of small bricks in layers to the thickness of 2½ feet. Three feet of fuel is placed between each tier of bricks, composed of Bazar sweepings, stable and cattle-shed litter, oplah, kundahs, (cow-dung and straw) and brushwood. The top being covered with the same and ashes, great care is necessary to render it impervious to rain, with clay, &c., till the fire has penetrated to a quarter of the length of the kiln, after which there is little fear.

The whole will take from six weeks to two months to burn out, but its form possesses the advantage of enabling the bricks to be taken out before the whole is burnt or about 15 days after ignition, and which permits the wind to drive the fire to the rear. The processes of taking from the mouth and adding to the rear are often going on simultaneously. Scarcely more than 75 per cent. of the best bricks is obtained from these kilns, the remainder are sold at remunerating rate, and so are the small bricks, serving to reduce the cost of the large, which at the principal stations vary from three to five rupees per thousand at the kilns according to the facility of obtaining litter from the public cattle stables, sheds and bazars, the demand for under-burnt and small bricks, and rent of brick land.

51. With the proper previous arrangement of the clay tables and moulding ground, contiguous to the drying ground, the following is about the amount of labor and fuel that the best bricks may require under proper supervision. An expert moulder will turn out on an average 1,000 bricks a day, in a month therefore of 26 working days, the total number moulded will be 26,000, and supposing the necessary precautions taken, 7 per cent. may be allowed for breakage, the total number for each moulder will be therefore 24,050; the cost of the raw brick on the drying ground ready for the kiln may therefore be reckoned as follows: for one lac or 1,00,000 bricks—

4 Tables or 4 moulders.
2 Bildars at the clay heaps will supply 4 tables.
4 Bildars for conveying.
4 Bildars at the drying ground.
4 Boys at the tables.

Moulds, table, barrow, boards, &c., 4 men for previous preparation of clay can dig and prepare in one month enough for 100,000 bricks or 13,000 cubic feet. The cost of burning will of course vary with the locality, and with reference to circumstances noted in para. 50; but for clamp-burnt bricks standard size, one lac will generally consume about 25,000 maunds of small combustible matter of kinds, and 120 maunds of wood.*

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* As prices of materials and cost of labor must vary with localities, it is useless to give amounts in money which could not serve as a guide to all, but known quantities may safely be stated, as most likely to produce similar results wherever they are similarly employed.

52. The goodness of a brick is tested by its regular shape, hardness and sound. It should have a metallic ring when struck, and bear more than one hard blow with the edge of a trowel before dividing. The compactness of the fracture will also indicate the quality and the degree of perfection to which it has been roasted, and it should but slightly absorb water. The weight of a firmly-moulded and well-burnt brick will vary according to the nature of the clay, the average is from 11½ to 14 lbs.

53. The clay-crushing rollers, of which mention was made in para. 32, are shown in (Plate 1, figures 10, 11, 12). They may be of iron or very hard stone, their length is 3 feet and diameter 18 inches, laid horizontally and close together. The outer ends of the axles turn in brass channels *f*, *f*, with a slight inclination towards the centres, and prevented from sliding when hard substances are being crushed, by preventive screws. On the inner ends of the axles at *b* are toothed wheels of same diameter as the cylinders. The axle of one is prolonged by a shaft about 20 feet long carrying at the extremity a levelled wheel *d*, worked by a motive-wheel *e*, 6 feet diameter, the axle of which is raised to the height of a horse's shoulder or bullock's neck, to which an arm is attached for cattle to be attached to. The motive-wheel is level with the cylinders and the connecting shaft supported midway as at *c*, in a block and brass box. Just below the rollers is, a pit to receive the crushed clay, and scrapers are so suspended under the rollers that their edges press against the surfaces of the cylinders, to scrape off all clay that adheres, which would otherwise clog the motion (figure 12). Counter-weights *a a*, are suspended in prolongation of the blades to keep the edges close to the cylinders.*

54. The pug-mill is shown at (Plate 2, figures 1, 2,) in elevation and section. It consists of a strong conical tub, 2 inches thick bound with iron hoops, generally 4 feet diameter at bottom, 3 feet 6 inches at top, and 6 feet high. It has no bottom, that being supplied by hard level clay ground, impervious to water into which it is sunk a little, and banked up to make it steady; *b* is a verticle square iron shaft, the bottom of which works in a cast-iron box *c*, let into a beam of seasoned wood in the ground; this shaft carries arms of wood or iron *d d*, and others in a cross direction *e e*, all of which are equipped with

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* From drawings taken during a visit to the brick-fields in Warwickshire, 1841-42. They may be arranged in one or two sets of two rollers each, according to the quantity of work.

iron knives, inclining in the direction the shaft moves, that they may have a tendency to lift the clay. By these two actions the lumps of clay mixed with water are effectually broken and the whole reduced to an uniform mass. An inclining scraper nearly equal to the radius of bottom of tub is placed at *f*, for the purpose of keeping the bottom free from adhesive clay. When sufficiently worked, the pugged clay is drawn off rapidly or slowly as needs be, by the sliding door *r*, received into a trough below, and carried away to where required. (Figure 2) shows how motion is given to the mill, the track of the cattle working which, should not exceed 16 feet in diameter or the motion will be too slow. The dotted lines on this figure show how a pump may be fixed, to be worked from the axis of the mill, for the purpose of affording a constant supply of water.

55. The nature and properties of soorkee or pounded brick, will be considered in detail when treating of "mortar," but it is in the immediate neighbourhood of the brick kilns that its manufactory should be located, because the broken bricks as they come from the kilns, instead of being carried to the works, which they often wastefully are, or otherwise lost sight of, can be made into soorkee and placed under sheds ready to receive it, or carted to the mortar trough as required. Only *pieces* of bricks of which there will always be plenty, should be used up into soorkee, and the fresh-burnt clay is not only easier to crush, but makes better mortar than when stale. A pair of crushing stones shown at (plate 2, figures 3, 4,) attached to each set of kilns will always keep up the supply needed, and the whole arrangement is fraught with economy as well as productive of good material. The stones should be fully 5 feet in diameter and 12 to 15 inches thick, working in a firmly set iron trough with a raised edge, and one oblique mouth for delivery of the soorkee as it is crushed out. The wheels are set on the same axle at different distances from the centre and scrapers of thin iron attached, to prevent adhesion of the soorkee to the surfaces of the stones.* The specific gravity of brick is 1·841; weight of a cubic foot 115 lbs., absorbs $\frac{1}{15}$th of its weight of water; is crushed by a force of 962 lbs. on square inch† if perfectly well burnt.

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* A steam engine of small power might be economically employed to work the rollers, pug-mill and crushing stones.

† Rennie.

CHAPTER III.

TILES.

56. TILE-MAKING requires, if possible, more care than bricks, as from their greater delicacy they are more liable to derangement. The clay should be much stronger than for bricks, very little sand being used, and that only for the very plastic kind. No ashes, chopped straw, saw-dust or any other foreign substance can be admitted. The best clay will generally be found below the brick soil, and the blue clay is particularly good for tile-making : the same previous preparation of the clay, and the same mode of working and tempering is necessary as explained in paragraphs 34 and 35, and the more effectually to render its state uniform and yielding so that in moulding it to the various forms required it may not crack, the pug-mill should be employed, (paragraph 54) from whence the clay should be removed to sheds under which the moulding is conducted.

57. Patterns in wood of the exact form of the tiles to be made, should be given to the moulders, as well as forms on and in which they are to mould the tiles, which will of course vary with the kind required, and should be of hard-seasoned wood of simplest construction, not liable to warp. These are the more necessary, and their use should be enforced to prevent a common practice of the natives of sticking on with water, strips of clay to the edges of a flat or sole piece to form the raised sides, which can be broken off by the finger and thumb when burnt, they should be made in one piece by the aid of a mould for the purpose, the edges being either turned up over a square edge, or worked into the sole, and the upper edge trimmed with an iron tool. The drying should be entirely in the shade in the hot weather, as from being thin, the tiles will warp if exposed to the sun, great care should be observed in laying them out

to dry, and when set firm, so to arrange them on edge that the air may have access to all their surfaces. A fence should encircle the drying sheds to keep out dogs and stray cattle.

58. There is not a material in use in India that requires more attention to improve it than the tile. The present almost universal kind, is light, porous, and absorbs water, is subject to be displaced by high wind or birds, and in the attempt to repair one of these biscuit-like tiles, a man in ascent and descent cracks 20 more. They are besides hardly weather-proof, and cannot, except in combination with that combustible and perishable material grass, reduce the interior of a building to a habitable temperature, whilst their diminutive size renders the use of a bamboo frame necessary, on which to lay them, which being perishable, rots, or is worm-eaten and sinks, the roof then leaks, its timber decays, and the goods contained in the building are damaged. In addition to which, the expense and trouble of their renewal is constant and great. These are surely reasons enough to show the necessity for the manufacture of a better description of material.

59. The natives burn their ordinary tiles with other pottery-ware in open clamps, but the flare oven shown in (plate 2, figures 5, 6,) is the best adapted for the kind of tiles about to be described. The walls are 2½ feet thick at the flues, and 14 inches at top, with a chimney hole 18 inches diameter in the centre of the vault. These ovens are 9½ feet interior diameter, and 10 feet high. The flues eight in number four feet high, and one and a half feet wide. Bricks may with advantage be burnt in these ovens with tiles; bricks are first laid in lines from the piers leaving the flues *a*, *a*, *a*, open to the centre and continued thus, up to the level of the tops of the flues, above that, they as well as tiles, are laid on edge about an inch apart in the way shown at paragraph 39, like basket-work, leaving the chimney well clear all the way. Two chains at the levels of *b* and *c* should encircle the oven to prevent its bursting. The fuel is only supplied to the flues, and the whole kept burning for three days, nor must it be opened till the oven is cool.

60. The marble tiles, which used to cover the Temples of the Greeks and Romans, have been successfully imitated in clay both in Europe and America, and are the very best that can be applied to the covering of buildings in India. They consist of flat tiles with raised edges extending from batten to batten on

the rafters, the joints being covered by others shaped like the half-frustum of a cone. For buildings where a moderate temperature is required, or which are intended to be inhabited, they should be placed over a layer of the common flat roofing tile $18'' \times 12'' \times 1\frac{1}{2}''$ with cemented edges, in a bed of fine concrete, $2\frac{1}{2}$ inches thick. For buildings intended as store-rooms, work-shops, stables and others of less pretension, they may be laid alone on the battens, the edges being cemented. (Plate 2, figures 7, 8,) show the mode of laying the tiles, (figure 9) is a plan of the flat tile 16 inches long, 12 inches wide at upper and 10 inches at lower end, $\frac{3}{4}$ inch thick, (figure 10,) a section of it. The raised edges are one inch above the sole, and extend to within three inches of the upper edge, being also $\frac{3}{4}$ of an inch thick. The line of lap is one inch below the upper end of the raised edges, or four inches from upper end of sole, and at this spot the width across between the raised edges should be $10\frac{1}{16}$ inches. The semi-cylindrical covering tile is shown at (figure 11), the body of which is 12 inches long and the neck three inches. At the junction of the neck with the body is a shoulder $\frac{3}{4}$ of an inch deep, and a bevel from that point *a* to *b*, of $\frac{3}{4}$ of an inch, this enables the round tiles to abut close to the soles of the underlying flat tiles at the lap, whilst a parallel bevel of the neck from *c* to *d*, keeps that part close to the overlying ones. Thus a close fitting joint is formed throughout, the line of lap of the whole ranging in a straight line. (Figures 12, 13,) show the transverse dimensions of the semi-cylindrical tiles, the thickness being half an inch; their form may be varied to that shown at (figures 14, 15.) The eaves may be finished by upright arris tiles plain or ornamented as shown at (figure 16) either cemented on to the cornice, or if made of wood, fixed on to the ends of the rafters. A plain Tuscan cornice may likewise terminate the eaves, the corona projecting well over, and under-cut to throw off the rain from the timber; or they may terminate in a gutter, and fascia of wood saturated against rot, or tarred. These constructions are shown at either side of (figure 17, plate 2).

61. One hundred of each, flat and semi-cylindrical, are required to 100 superficial feet of roofing, together with 10 larger adapted to the ridge, their weight is—

100 flat tiles, ...	650 lbs.
100 semi-cylindrical, ...	400 „
10 ridge, ...	45 „

Of the flat tiles 18″×12″×1½″ for the cooler kind of roof, 67 will be required to 100 superficial feet and their weight 1010 lbs. The concrete and cement for the same space will weigh about 2075 lbs.

62. There are many varieties of tiles, one is shown at (plate 2, figure 18,) which is an imitation of the antique, the flat and semi-circular being formed in one. (Figure 19) is another variety, being a curved tile, the joints covered with the same. (Figure 20) is a wavy or pantile, lying like the plates of chain-mail. The fillet that bounds the concave sides is so formed as to hook well over the adjoining edges, in which case only will the lap be secure, great care is necessary in the formation of this tile and fillet; none are however to be compared to the first mentioned, either for security or durability.

63. During the season of manufacture, it would be found advantageous to make a number of flat rectangular tiles for both paving and roofing, with reference of course to the probable demand, but in some large stations they are constantly required. The sizes recommended are 12″×12″×1½″ when burnt, which answer for both paving and roofing, but for the latter work, it will be found more economical in timber to make some 18″×12″×1¾″ especially where they are required for a sloping roof to be used as an under-layer to the tiles described in para. 60.

The red color of tiles in a series of buildings is glaring and unpleasant to the eye, to relieve which, as well also as to improve still further the temperature within, they may be colored after the roofing is complete, by coating them over with common bazar paint, sanding them whilst the paint is wet, or they may be slate-colored previous to burning by the following process—

2 Parts dry tile clay,
4 Parts potter's lead ore (galena),
1 Part oxide of manganese,

each to be reduced separately to powder, and then mixed to the consistency of cream. The tiles when dry to be washed over with the above.* The lead ore will answer nearly as well alone, if the manganese is not procurable.

Whenever tiles are to be glazed, the glaze being put on, the tiles are put in a potter's oven till the composition begins to run. One kind of glaze is made from, what are called lead ashes, being lead melted and stirred with a ladle till it is reduced to ashes or dross, which is then sifted, and the refuse ground on a stone and re-sifted. This is mixed with pounded calcined flints. A glaze of manganese is also sometimes employed, which gives a smoke-brown color. Iron filings produce black; copper slag, green; smalt, blue. The tile being wetted, the composition is laid on from a sieve.

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* Communicated by Mr. Aikin, F. R. S.

64. Bricks have within the last few years been made with machines, and though much want of success was at first experienced from the difficulty of forcing the bricks out of the moulds as they were formed, yet latterly Hunt's and also Hall's machines have been brought into tolerably successful operation; Hall's machine at Roorkee makes 11,000 bricks a day, with the following establishment attached under an experienced Overseer:—

1 Tindal.
26 Bildars.
4 Bullocks.

The subject of brick making by machines was fully discussed at a Meeting of the Civil Engineers' Institution in London, on 25th April and 2nd May 1843, and many arguments advanced both for and against. Those "for" are, 1st.—The reduction of cost in moulding, if the first cost of the machine is not very heavy and hand or horse-power alone required. 2ndly.—The greater density and uniform quality of the bricks. The arguments "against" are, 1st.—That as the cost of moulding is only a small proportion of the whole manufacture, the saving by machinery is small. 2ndly.—That bricks compressed by machines are very difficult to dry, the outer surface dries and scales off sometimes before the evaporation from the centre is complete. 3rdly.—From their great density that mortar would not adhere so readily to them, and 4thly.—From their hardness and weight they would be difficult to cut. It may be inferred therefore, that not very much advantage is gained by the actual moulding by machines, if the processes for the preparation of the clay and the use of crushing-rollers and pug-mill be introduced, previous to the moulding. For tiles, column, arch, and moulding bricks, doubtless the machinery would be advantageous.

CHAPTER IV.

ON THE CHOICE, PREPARATION, AND APPLICATION OF CALCAREOUS MINERALS, FOR MORTARS AND CEMENTS, WITH NOTICE OF THE MANUFACTURE OF ARTIFICIAL STONE.

65. Calcareous minerals are composed essentially of carbonic acid and lime, such are pure limestones, which dissolve either wholly or in part, in weak acids, with more or less effervesence. Limestones are not always pure but are often combined with silica, alumina, magnesia, oxydes of iron and manganese, and bitumen, the presence of one, two, or more of these substances forms the various kinds of limestones.

Limestones are generally arranged into four classes, of which the first is marble and white chalk, the former never, and the latter seldom used for mortar. Grey limestone is also of this class, containing not more than 4 per cent. of clay, and forming beds in the mountain limestone very hard and often containing coral and organic remains. These generally furnish common lime. The second class is the bituminous, of dark brown color, but calcining to a pure white, the black marbles are of this class. The third class is formed of magnesian limestones, its repository being the new red sandstone of geologists immediately above the coal measures. The fourth and most valuable class are those stones containing a large proportion of clay; such are grey chalk, the bed of which contains no flint, and is harder than the chalk above it. The blue limestone is the best, often of a dark dove color and dull aspect. It forms beds in the transition and mountain limestone, and its geological position is between the oolite and new red sandstone, its direction oblique.

OF CALCAREOUS MINERALS.

66. Lime is divided into two classes, "common lime" and "hydraulic lime," the former applicable only for dry situations and inferior work, the latter having the property of setting under water, is used in foundations, damp situations, terraces, floors and hydraulic architecture in general. Some limes are naturally hydraulic, and the mode of testing such properties will be presently shown, others are made artificially so.

Although the following tests are an approximate guide to the mode of investigation of the physical characters of the mineral substances; experience by actual trial should, in most cases, be resorted to.

67. That a mineral belongs to the calcareous class is easily determinable, by immersing a small fragment in dilute muriatic acid* or vinegar, the effect will be as stated before, or by trying to scratch it with an iron point to which such mineral will yield. Natural hydraulic limestone may be partially known by application to the tongue, or by the smell when wetted, when the presence of clay will be detected. Natural limestones often contain earthy or metallic oxides, which by calcination combine with the lime. Whence result modifications in its properties. Thus it is known that lime will remain a fat lime so long as the foreign substances do not form a tenth of its weight; but beyond that it becomes meagre, that is to say, it swells much less on slaking; and, if amongst these foreign bodies, silex should predominate, the paste, with or without sand, will acquire the property of hardening in water. Having established these facts, the best test of its qualities is to take small fragments of about 1″ or 1½″ cube and put them into a baked earthen vessel pierced with holes exposing them to the heat of a common wood fire, in a stone or lime kiln with wood fuel till properly calcined. The calcination will probably take from 15 to 20 hours, and in order to make sure of its proper calcination, subject a small portion to trial by slaking it and adding dilute muriatic acid, if burned enough, it should dissolve without effervescing. It should then be carefully slaked by immersion for a few seconds in a linen bag or

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* Equal parts of acid and water.

basket in pure water[*] and kneaded into a stiff clayey consistency, by means of a pestle and mortar of either stone or iron. Some hydraulic cements will not slake till pounded previously to an impalpable powder, so that if the mineral be proved to be calcareous, and it slakes but imperfectly, it must be so treated. Thus prepared, it must be left to complete the development of all its parts, which will be known by its becoming quite cool, and this will take probably two, three or more hours. It must then be formed again to a stiff paste, adding a little water if required, and finally placed in a vessel similar to a China mustard pot, having as much width as depth, filling it about ⅔rds, then immerse it in water, noting the time of immersion. The quality of the lime will be inferred from the promptness of induration. Or the experiment may be made as recommended by General Pasley, by reducing the specimen to powder when burnt, then take 2 oz. of the powder and ¾ oz. of water, mix with a knife, then knead it with the hand into a ball, which will take about 20 minutes. It will become warm, and if a good water cement, will harden as it heats, or if put into a basin will continue to harden. It should not be put into water till it has began to cool after attaining its greatest heat.

68. Common lime will retain the same consistency for years after immersion. Hydraulic limes set after six or eight days, continue to harden, and in six months will be like soft stone, water will then not act on it. Eminently hydraulic limes will set from the second to fourth day after immersion, and in one month are very hard.[†]

Magnesian limestones which make not good water cements[‡] may sometimes be mistaken for fine-grained sandstone, but on close inspection small rhomboid chrystals will be found, which are compounds of carb. lime and carb. magnesia. These stones will not readily effervesce in cold muriatic acid, but rapidly in hot acid; and after exposure to a red calcining heat for some hours, will not readily combine with water.

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[*] Various phenomena are exhibited by the immersion. It either hisses, decrepitates, swells, gives out vapours, and falls to powder instantly, or remains inactive for five minutes, and then shows the above symptoms, or it may exhibit no alteration for a quarter of an hour, begins to smoke and crack without decrepitation, and sometimes the phenomena will not commence for an hour or many hours after immersion.

[†] Scientific treatise on mortars and cements, by M. Vicat.

[‡] A fine quality of magnesian limestone was determined by the Commissioners for re-building the Houses of Parliament to be the very best for the purpose, being close-grained and its particles remaining undisturbed after trial by immersion in water, whereas other stones after similar trial gave more or less sediment.

Naturally hydraulic limes are those included in the fourth class before mentioned, after calcination fall into a powder of a buff-colored tinge, as they contain a large proportion of clay.

69. Thus the fittest material for hydraulic purposes neither depends on the hardness of the stone, the thickness of the stratum, the bed in which it is found, nor its containing some clay, but in the color of the powder after calcination and its containing much clay. Alumina alone has no power to render lime hydraulic, but silica is an essential ingredient in hydraulic limes. The oxides of iron and manganese have no influence on the hydraulic properties; hence the most part of the calcareous minerals used for such purposes, are compounds of carbonic lime and clay in various combinations, and the quality depends on the relative proportion of these two substances. The above tests alone can determine the quality of lime furnished by any minerals. Limestone with ·06 of clay produces a sensibly or slightly hydraulic lime.

Limestone with ·15 to ·20 hydraulic lime.
Ditto· ·25 to ·30 Eminently hydraulic lime ("Vicat.")

70. Careful analysis and experiments of late years have settled the question that the presence of Argile (clay) in the stone is the cause of its possessing important quality of indurating under water, but whatever may be the solidifying principle, an artificial hydraulic lime may be made equal to any naturally so, by mixing with common lime slaked, any mineral substance of which clay is the predominant constituent (*vide* Art. cements ante) and calcining the mixture, or by exposing the foreign substance to a suitable degree of heat, reducing it to powder and mixing with the slaked lime. A common method is by taking 80 parts of unslaked lime, and 140 of uncalcined mineral,* but if the carbonate of lime should be at all mixed naturally with clay, then 15 parts of clay will be sufficient. It is proper however to determine the proportions for different localities, as some prepared cements contain varying parts of the two substances; a quick setting cement exported to India called "Parker's patent cement" contains 45 per cent. of clay to 55 of carbonic lime, and so

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* If the lime is slaked the proportion should be 110 parts ("Pasley.")

different may be the chemical properties of apparently similar materials, that the result however successful in one place should scarcely be trusted without due investigation in another. The above facts may however serve as a guide for the mixture of the ingredients. Particular care should [illegible] paid to amalgamate the materials well, and to the degree of calcination best suited to the compound.

CEMENTS.

71. Cements are of two kinds, natural and artificial, either of which may be combined with common or slightly hydraulic limes in the formation of good water cements, or may be used by themselves either as binding matter, or for plaster work.

The natural cements are non-calcareous substances, of these the puzzolana or volcanic ashes, extends largely into the excellent cements of former times, tarras also, a blueish lava found on the Rhine, and used in the water buildings of Holland. In England a species of basalt, whose composition is similar to the tarras, is used for the same kind of work mixed with lime. The elements of these productions are nearly as follows in 100 parts:

Silica, ...	55 to 60	parts.
Alumina	20 to 18	"
Iron, ...	20 to 15	"
Lime,...	5 to 6	"

Monsr. Sganzin gives the following Analysis of Tarras and Puzzolana.

	Tarras.	Puzzolana.
Silex, ...	0·570	0·445
Alumina,...	0·160	0·150
Lime, ...	0·026	0·087
Magnesia, ...	0·010	0·049
Oxide of Iron,...	0·050	0·120
Soda, ...	0·010	0·040
Water, ...	0·096	0·092

"Sganzin cours de construction."

The object to be aimed at in manufacturing cements is to replace the above volcanic productions by an artificial substance as nearly equal in quality, and at as small an expense as possible to form a good hydraulic mortar.

72. The clays appear to lend themselves with much facility in the transformation;* common potter's clay, in the composition of which the alumina is about $\frac{1}{3}$rd the silex, with $\frac{5}{100}$dth of lime, furnishes an excellent artificial puzzolana when properly calcined, which should be to a cherry-red color. When the clay contains more than $\frac{1}{10}$th carbonate of lime, it will form a better cement by only slight calcination, when none, it will bear an active heat.† Direct experiment should be resorted to in order to prove the degree of calcination to which each kind of clay should be exposed, for this purpose three samples of it should be submitted to such a temperature as will convert one into a pale-brick color, a second to a cherry-red, and the third into a hard-brick without vitrifying it. If a current of air be passed over the clay whilst calcining, it will be found that the mortar made of such will harden much sooner and be stronger. A mortar composed of equal parts of lime, sand, and the cement should then be prepared, and the three specimens placed under water, when the quickness of induration will prove the quality. A comparative value of cements may be ascertained by observing which will harden with most sand. The best manner of ascertaining whether a lime is hydraulic, is the following: take quicklime as it comes properly calcined from the kiln; reduce it with water to a thick paste, and place enough of it on the bottom of a tumbler to fill it for one-third or one-half of its height; three or four hours after fill the tumbler with water and leave it at rest; after two or three days touch the lime lightly with the finger, to ascertain whether it begins to harden: if it be very hydraulic, it will have taken after eight or ten days, such a consistence, that no impression can be made on the lime by pressing strongly with the finger. We should assure ourselves whether there has been, in fact, no impression, by throwing off the water and washing the surface of the lime, which will be covered with a thin layer of lime softened by the immediate contact of the water. If the above result be obtained only at the end of twenty, thirty or forty days, the lime should be

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* M. Vicat mentions besides the yellow psammites and some species of schists.

† General Treussart on calcareous minerals.

regarded as only feebly hydraulic, and if there be no consistence in the lime after the lapse of about forty days, it cannot be regarded as at all hydraulic.*

The full power of a cement can only be known by joining half a dozen bricks together and projecting them perpendicularly from a wall supporting them till dry. At intervals of a few days add another brick till 20 project. It is a poor cement that will not bear that number in a fortnight.†

73. Pulverized tiles or bricks, if the clay of which they are composed is as above, and free from sand, will answer the purpose, but as these materials are often indiscriminately used, the clay being impoverished by sand, or merely a stiff earth having been used in the manufacture, it is impossible that good hydraulic mortar or cement can result. Such is generally the practice in the Department of Public Works, and the pulverized brick, or "soorkee" as it is termed, is not often fit for the purpose, and the mortar being used too without sand, the color is tinged red or yellow, according to that of the bricks. These remarks however show the necessity of attention being paid to the quality of the soorkee, and as the brick kilns when unloaded present broken portions of various degrees of hardness, that kind can be selected which is most applicable to the mortar intended to be made. If the clay from its admixture with sand is not fit for cement, some bricks might be made of pure clay and burnt in the same kiln with those made for masonry purposes, and made into soorkee when the kilns are opened. "Mortars made from limes mixed with ordinary brick-" clay and subjected to experiments sustained only 44 lbs. before breaking after " 28 days' induration under water; whereas mortars made from hydraulic limes " composed of purer clays carefully sought for, bore from 110 to 190 lbs. after " induration from 16 to 20 days," such are the facts recorded, by Col. Totten, of the American Engineers, at page 37 of his work on mortars, he also states at page 66, that "limes mixed with good brick-dust, but slightly burnt and allowed " to indurate for 11 days bore 330 lbs., whereas the same limes mixed with the " same kind of dust from bricks more highly burnt, bore only 180 lbs., and that " results in the same proportion were obtained from the dust of tiles slightly " and well burnt." This shows how important it is not to use soorkee or brick-

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* Treussart on Mortars, p. 16.

† General Pasley on Cements.

dust at hazard, and that no so-styled hydraulic mortars should be used without subjecting the ingredient as well as the composition to careful experiment.*

By means of a very simple chemical process, it may be ascertained before hand whether bricks but little or highly burned, should be taken. Take a little of the crude clay, or a little of the brick-dust, put it in a glass and pour over it a little diluted nitric or muriatic acid, or even strong vinegar ; should there be no effervescence; it is proof that the clay should be highly calcined to give good cement. Should there be considerable effervescence, it is because the clay contains a notable quantity of carbonate of lime. To determine nearly the quantity of lime, a little of the clay, having been dried by a gentle heat, must be weighed ; it must then be diffused through a small quantity of water, and muriatic acid be poured on little by little, as long as there is any effervescence; it should then be filtered or gently decanted, the residue washed in a large quantity of water and again decanted. This residue being then dried by the same gentle heat as at first, must be again weighed; if the weight be less by one-tenth than at first, it is a proof that the clay contained that quantity (about) of carbonate of lime, which has been dissolved by the acid. In this case bricks but lightly burned must be taken; and so much the less burned as the loss of the clay, by the acid, shall have been the greater. If the clay lose only four or five per cent. of its weight, the bricks which are called "well-burned bricks," should be preferred. In addition to the chemical trial just ascribed, it will always be proper to make the trial first explained, that being the most certain.

74. The following is taken from the results of a number of experiments carried on by General Pasley at Chatham, for the purpose of ascertaining the best mode of preparing artificial cement.† 1st. White chalk of the Geologists which is pure carbonic lime, is found mixed with flint; the flint is to be separated and the chalk ground to an impalpable powder, or to a paste by aid of water. The impure chalk from the surface of the ground must not be used.

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* The experiments were made on quadrangular pieces of mortar moulded 8″ long and 2″ scantling, supported at the ends, whilst to the middle was suspended a collar and scale for the weights.

† The difference between "Water Cements" and "Hydraulic Limes," must be here stated, the former being calcined stone reduced to powder mixed with raw clay, and then re-kilned, and the latter being lime and clay separately calcined and mixed afterwards.

2nd. The blue alluvial clay of lakes or rivers which must be quite free from sand, the brown surface being rejected, and care taken not to allow it to get stale by exposure which robs it of its blue color and good properties.* Where blue clay cannot be had, fine pit clay may be used. The proportions of the ingredients are 100 lbs. pure dry chalk to 137½ lbs. fresh blue clay, being equal to 4 parts of chalk to 5·5 of clay by weight, which is nearly equivalent to 1 cubic foot of chalk paste with 1½ of fresh alluvial clay, the consistency obtained by mixing 1 lb. chalk powder with 7½ cubic inches of water, so that there will be 96 lbs. of dry chalk to every cubic foot of water. If the under strata of grey chalk or pit clay be used, other proportions will be necessary and experiment must determine them.

If limestone is used instead of chalk, 40 lbs. of lime fresh from the kiln as quicklime must be added to 100 lbs. of clay.†

The chalk must be ground (using a little water as it will not grind in its natural state) in any mill fit for the purpose, the one used by General Pasley, being an iron vessel in which two iron wheels 4½ feet diameter worked, placed at unequal distances from the centre, one near the outside and the opposite one nearer the pivot, like the soorkee mill, plate 2, figures 3-4.

After being ground the superfluous water must be drained off, and the paste brought to a proper consistency. It must then be mixed with the clay by means of two little measures which must be as 1 to 1½. Let the contents of these be thrown into a pug-mill, such as is shown in (plate 2, figures 1-2) and described in para. 54, which is of larger dimensions however than is here necessary, being for mixing mortar.

The ingredients of the first mill-full should be passed through twice, and then fresh chalk and clay paste, gradually added in the above proportions.

The raw cement must then be made into balls of 2½ inches diameter and allowed to dry so as not to stick together, exposure for 48 hours under cover from rain will do.

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* The addition of not less than $\frac{1}{16}$th of the whole compound by measure of pounded charcoal or other combustible matter, such as resin or saw-dust, will restore the virtue of the clay, to be added to the raw mixture, if it should have got stale.

† Let the lime be weighed in portions of 39 lbs. and mixed with sufficient water to make lumps of slaked lime paste, 24 hours after mix each lump with 1 cubic foot of clay, incorporate in the pug-mill, and make into balls similar to those of chalk compound.

The kilns for burning the cement may be inverted conical, frustum-shaped lime kilns, in size varying according to circumstances. For experiments, such a one as shown in (plate 3, figures 1-2) (Pasley's) made of sheet-iron may be used, the height of fuel and layers of cement are shown. The fire is first assisted by a bellows, handle A is to keep the door shut, which is hung on by a hook and can be taken off at pleasure. The bottom of the kiln is laid with shavings, and then coal and cement balls laid on in alternate layers, three days after lighting, the calcined cement may be drawn, and more raw material supplied at top.

The kiln should be drawn once in 24 hours.

The cement must afterwards be ground in a mill.

SAND.

75. Sand used in making mortar should be sharp, *i. e.*, angular, and quite freed from all earthy matter, retaining nothing but pure silicious particles. Pit-sand is generally superior to river-sand for works of great strength on account of its being more porous and sharp, the angles of the latter being sometimes worn by attrition; river-sand being generally finer may be used for plastering interiors.

Pit-sand should be cleansed till it leaves no stain on the fingers when rubbed between them.

With regard to the action of lime on sand, there is no chemical combination between the two, the union is mechanical, the lime entering the pores of the sand, and, connecting the particles in the same way as those of granular stones, are connected by natural cements, sand serves the important purpose of causing uniform shrinking in a mass of brick-work, and is conducive to solidity and economy from its superior strength. The intimate mixture of the sand with the lime is an important consideration, which should be effected with but a moderate quantity of water, the proportions of sand however with the different kinds of lime form the subject of chief consideration, and as sand is the cheaper article of the two, there may be a temptation to excess on this side on the part of native agents and masons, it becomes therefore a matter of moment that the admixture of ingredients be well looked to by the Engineer anxious to secure efficient work.

Monsr. Girard de Caudemberg, Engineer of Roads and Bridges in France, published in 1827, an account of a certain sand which he calls aréne, which possessed the property of forming a paste capable of assisting in a great degree to harden hydraulic mortar under water. It varied in color from reddish-brown to yellowish-red and ochreish-yellow; thus proving, as was also ascertained by analysis, that the sand was mixed with clay in certain proportions, and in eight kinds he found that the proportions of clay varied from 10 to 70 per cent., some were calcareous, but more frequently silicious or mixed. They were generally found on hillocks forming the basins of rivers and brooks, and rarely in vallies. In the absence of hydraulic lime, Mr. Girard formed concrete with a composition of common lime pebbles and aréne, that, a year afterwards required the aid of stout pick-axes to break it up. These arénes resemble in the description, substances in India, particularly in the Gwalior, Malwa, Saugor and Bundelkund districts, superimposed on masses of large argillacious tufa, and doubtless varieties exist in many other localities, and would be extremely useful to combine with common limes.

MORTAR.

76. The experience of Smeaton has confirmed what was an ancient practice, and which should not be lost sight of, *viz.*, to beat mortar for a long time with a heavy pestle just before using, not only more thoroughly to incorporate the ingredients, but to dispose them more rapidly to consolidate.

The best proportions for the ingredients of mortar can be ascertained only by experiment, varying of course with the qualities of the limes. Regarding the lime as simply a cement binding the particles of sand or soorkee, (indifferent puzzolana,) the proper proportions will appear to be those in which the lime is sufficient to fill up the voids between the particles, this quantity may be ascertained by filling a measure, first with sand or soorkee and then pouring in as much water as will fill up interstices, by which means the bulk of lime will be known. The quantity of water should be measured previously to ascertain what proportion is expended. From a number of experiments the proportions with common lime, appear to be from 2 to 3½ parts of sand to 1 of lime by measure, with sufficient water to form a ductile paste; for a superior mortar 1 part of lime, 1½ to 2 of sand, and ½ to 1 of artificial puzzolana or pure calcined clay, before treated of.* Mortar for hydraulic purposes is stated by Smeaton to be best when equal parts of lime, sand, and puzzolana,† are used. Mr. Vicat is of the same opinion as regards the slightly hydraulic and hydraulic limes.‡

Powdered forge scales, such as fall from the anvil at a smith's forge form an admirable ingredient in hydraulic mortars, and may be used in lieu of, and in the same proportion as the puzzolana with hydraulic limes. No architects or engineers of the present day entirely dispense with sand, using it nearly in the proportion above-mentioned, but puzzolana should not be added in excess when the ingredients of mortar are lime and sand only, so that whatever proportion of sand is known to make good mortar with common lime, the quantity of puzzolana to render it fit for hydraulic purposes must be deducted from the said proportion of sand. It should be borne in mind that the best mortars for withstanding the vicissitudes of the weather, and of acquiring great hardness, are those composed of pure quartzose or granitic sands and of the hydraulic or powerfully hydraulic limes. It is certain that the poorer limes (such as dissolve in water to the last grain and whose volume is doubled by slaking,) and their admixtures ought for ever to be prohibited from works of any importance.§ In India, chalk is not to be procured in abundance, and then it would be necessary to mix fat lime with clay, and to give a second burning for the mixtures, which will cause embarrassment, and an augmentation of expense; in such cases, there will generally be economy in making hydraulic mortar at once of fat lime, sand, and artificial puzzolana, and besides, the relation of the resistance of these two kinds of mortar, is no unimportant consideration. If we compare the results obtained from experience, we shall see that the mortars made of sand and hydraulic lime, whether natural or artificial, afford an average resistance hardly amounting to 220lbs., while it is 352lbs., for the mortars made of fat lime, sand and both natural and artificial trass. To compare the expense justly therefore, it would be necessary to lessen the proportion of trass, substituting sand, until we arrived at an equal resistance; where there are good natural hydraulic limes, they should be used in preference to fat lime, which requires always to be mixed with natural or artificial trass, for constructions in water or in damp places. When, however, works demanding great care, are to be made, it will be proper to add to the mortar a little natural or artificial trass. The proportion to be added depends on the quality of the hydraulic lime and of the trass, if both are of good quality, and if it be known, for example, that the lime will bear two and a half parts of sand, and half a part of fictitious trass. This small quantity of trass will not much augment the expense, and will always correct the bad effects resulting from portions of the lime having been too much burned, or impaired by exposure to the air.

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* General Pasley remarks that the parts should be by stricken measure for the sand, and that the lime be measured in lumps as it comes from the kiln without slaking or breaking. Smeaton measured his ingredients dry, the lime being in powder, thrown into the measure not pressed down, but stricken.

† As the word "cement" is applied to a separate compound of lime and clay in this treatise, as well as to puzzolana natural and artificial, the term "puzzolana" (calcined clay or soorkee) will be used for the future in speaking of the ingredient for the formation or improvement of lime for hydraulic purposes.

‡ When expense is no object, the result of Smeaton's experience on the "Eddystone" may be assumed as the best for hydraulic mortar, *viz.*, that the lime and puzzolana alone in equal quantities made the strongest, it is however very slow in hardening.

§ "M. Vicat treatise on mortars and cements."

77. The bad qualities of the ordinary limes may be in some degree corrected by the addition of a small quantity of coarsest sugar (goor): this is not an uncommon practice in India. Its aid is chiefly confined to the hardening the outer surface of the last coat of plaster, which is effected by employing a strong solution, and rubbing well with wooden floats for a long time. There need not be more than about a pound weight to every 10 gallons in mixing the stucco. Artificial cements, such as are described as manufactured by General Pasley, (para. 75,) appear to be strongest when used pure, whether as mortar or stucco, but as few situations will warrant such expense, sand may be used without much deterioration of the adhesive qualities. Experiment here also being the best guide. Mortars, whether composed of lime and sand, or lime and soorkee, often exhibit a mottled appearance on first drying, which proceeds partly from the injurious effects of alternate moisture and dryness. The phenomenon consists of a distinct exhibition of the courses of masonry through the plaster, indicating at one time an excess of humidity in the spaces, and at another time in the joints. Early decay in plaster of a similar kind, especially near the base of a building, may often be observed.

78. The effect of dry spaces and moist joints proceeds from the spongy nature of the bricks, which unless well saturated with water before using, and

at the time, cause the plaster to part more speedily with its moisture in those parts over them. After the same plaster has dried, if the situation be damp, the appearance will be reversed, if the bricks are ill-burnt; in this case they suck up more moisture from the earth than the plaster, and exhaling it during hot weather exhibit damp spaces, the joints remaining dry. Plaster, covering walls of brick cemented with clay, will always exhibit dry spaces and wet joints for a long time after rain, as the cementing matter will imbibe the moisture more rapidly than the bricks, such works so plastered are subject to early decay, and independent of the ruin of the plaster and expense attendant thereon, the unsightly appearance should be a stimulus to the prevention of the evil, by the proper preparation of both bricks and mortar.

79. It may be as well to treat here of the proper mode of plastering a brick surface, as the subject is so intimately connected with the ingredients employed; for this purpose the sand should be more particularly cleansed from all impurities.

The wall should previously be well wetted, and dry joints scraped out, the first coat is then laid on, consisting of about one part of lime, two of sand and a proportion of bullock's long hair, or cotton refuse, freed from all greasy matter or saline particles, laid on about $\frac{3}{8}$th of an inch thick and allowed to dry nearly before the second is laid on. The first coat is scratched diagonally all over and crossed, these scratchings should be deep, and with rough edges, in a kind of dove-tail shape, to form a key for the second coat to adhere to, this is of the same component parts as the first, only with much less hair or cotton, laid on with a floating trowel and of the same thickness as the first, brought to a level surface with rules or straight edges. The third coat is laid on most carefully and composed of the finest lime, the proportion of lime and sand (without hair) being such as will form a putty when well macerated, this will vary from 1 of lime to 2 and $2\frac{1}{2}$ of the finest and whitest sand, to equal parts of each. The lime slaked by immersion, (see mode of slaking, para. 87,) and the putty protected from the air till wanted. A stucco, such as is below mentioned, may be used for very fine work as a third coat. Particular care should be taken to have all the ingredients well beaten together and mixed in the manner described for making mortar.

Good water cement mixed with coarse sand is far more suitable for stucco than even the best limes.*

Cement stucco should always be completed in one coat, as the first will set too rapidly for a second to be laid on so as to adhere. A very excellent stucco may be made similar to that used in England, by a mixture of 14 lbs. of the best stone lime, 56 of coarse, and 42 of fine sand (both washed) and 14 lbs. of calcined bones reduced to ashes. For a fine texture the coarse sand is to be omitted, and 98 lbs. of fine sand used, with 15 of lime and 14 of bone ashes.

The lime should be slaked by immersion, *i. e.* the quicklime plunged into water for a few seconds, and withdrawn before it commences to slake; it hisses, splits with noise and falls to powder, and may be kept for some time.

80. For the protection of stuccoes and plasters from the effects of the weather, in buildings of importance, the following compositions are useful, laid on with a brush, the surfaces being perfectly dry before the application; three parts of oil heated with $\frac{1}{8}$th part of its weight of litharge (moorda sung) and one part of wax; or one part of linseed oil, with $\frac{1}{10}$th of its weight of litharge and from two to three parts resin. A single coat is sufficient. Premature decay often takes place in plasters and stuccoes, against which, an exposure of the causes may lead to a precaution. The primary cause is the presence of earth and decayed vegetable matter in the sand used, to this may be added impurities of argillaceous matter in the lime, and an improper mixture and proportion of lime and sand. Moisture is the exciting cause, but failure would not be so frequently exhibited, if the corona of cornices and copings were not improperly made with horizontal under surfaces, which do not permit the rain water

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* The celebrated Madras chunam is a stucco laid on in three coats, the first, a common mixture of shell lime and sand, tempered with "jaggery water" (sugar solution) and about $\frac{1}{2}$ inch thick. The second of sifted lime and fine white sand also sifted, this coat as well as the third, is applied without jaggery water, only on account of its color. The last coat is prepared of lime from only the purest and whitest shells, and none but sand of the whitest kind, and of that but a proportion of about $\frac{1}{6}$th. The ingredients of the third coat are ground with a roller on a granite bed to a paste of the consistency of cream. To every bushel of this paste is mixed, the whites of ten or a dozen eggs, half a pound of ghee, a quart of fresh cards, and a quarter of a pound of (soap-stone) "balapoong." The last coat is laid on exceedingly thin and before the second is dry; it dries quickly and is rubbed afterwards with a piece of soap-stone or agate to produce a polish, an operation, which is continued for some hours, after which it is necessary to wipe it with a cloth from time to time, to remove the exudation which continues for a day or two after completion.

to drop clear of the wall. Heat will thus often call the vegetative impurities into action, and a green deposit is the consequence.

A sweating of plaster work may often be observed, this is an efflorescence of substances which do not enter into combination with lime, such as grease, which should be avoided; aluminous matter is sufficient in the preparation of particular stuccoes without the addition of ghee, &c., though bullock's blood has been used with good effect in compositions of the kind.

With reference to the properties of cement as before stated, effective and pleasing cornices and mouldings, may, under some circumstances, be formed of naked brick, which set in cement with judicious management, would add to the appearance as well as the durability of brick-work without the aid of the plasterer.

81. From what has been already said, the good qualities of mortar depend on the kind of lime, the hardness, roughness, and porosity of the sand, and the care in mixing the ingredients properly and sufficiently. . The proper preparation of mortar for any purpose, consists in—

1*st.*—The selection of the material.

2*ndly.*—The modes of calcining, being the form of kiln, degree of heat to be applied, and nature of fuel.

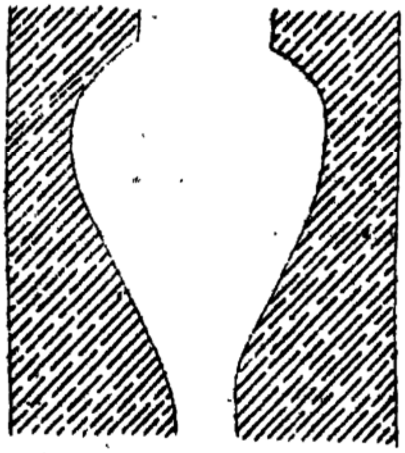
3*rdly.*—The slaking and proper mixing of ingredients.

Mention has already been made of the means of selecting the calcareous substance, and of their classification for common or hydraulic purposes. We will therefore proceed to the second article.

82. *Calcining.*—The limestone should be reduced as small as is consistent with due economy, the hardest kind to about 3″ diameter and the softer in proportion.

Where practicable, it is advantageous to construct the kilns as near the place whence the raw material is dug as possible, as it burns better when retaining its natural moisture, otherwise its calcination will be much improved especially in dry hot weather, by sprinkling it well with water before loading the kiln, and by the addition of water from time to time on the faggots at the eye of the kiln. It may be as well also to mention that it is advantageous to use lime as soon after it is burnt as possible. Pure limestones (containing no clay) may be brought to a white heat without inconvenience. Hydraulic or compound limestone requires certain precautions, and should not be carried beyond a red heat, it will, if overburnt, present a heavy dark color, slakes with difficulty, or not at all.

It is very easy to judge if the stone be properly calcined, by taking from the centre of each of a few samples a piece as big as a pea, drop each separately into weak muriatic acid, and if no effervescence takes place, the burning is complete. Various are the forms of kilns, as the minerals themselves, those only that bear the concurring testimony of the most experienced practitioners, are such as shall be treated of and may be considered standard examples. First however let the young Engineer be warned against the egg-shaped Section shown in the margin, as owing to the sudden contraction of the mouth, the flame rises with force by the circumference whilst the inner portion remains badly burnt. The capacity as well as the form of a kiln contributes to the proper calcination of the material. (Figures 3, 4, plate 3,) are those which have furnished the best results. No. 3 being that wherein wood and such like fuel is consumed, and No. 4, where coal is specially used. Coal, charcoal and oplah, &c., in alternate layers [illegible] hereafter explained, may also be used in No. 3, but wood never in No. 4. The interior of a kiln should be constructed of the hardest bricks, or other material unalterable by heat, and cemented through a thickness of 12 inches, with a mixture of sand mixed with refractory clay. The dimensions are given in the plates.



83. The kiln shewn at plate 3, (figures 6, 7, 8,) called a flare or dome kiln, is used by the most extensive lime-burners in Dorking, and is similar to all those used in the vicinity of London, only they are some times placed in pairs or three or four together; this arrangement, by exposing a less surface of wall to the cold air, slightly diminishes the expenditure of fuel; but it is probably adopted more with a view of saving labour than fuel, as the fire-man has all the fires under his immediate control. The interior of the kiln is of a circular, bottle-shape, the diameter at the bottom being 10 feet 6 inches, the wall is carried up plumb to a height of 7 feet, at which point the dome is commenced, which closes in the kiln, leaving only an opening at the top 1 feet 8 inches diameter

and 2 feet high, as a chimney, the total height from the hearth to the top of the chimney being 19 feet 6 inches. The thickness of the brick-work to a height of 11 feet, is 14 inches, which is the level of the top of a surrounding wall of rubble work; from this height to the top the thickness is 9 inches, including the lining of fire-brick. The surrounding wall of rubble is of a horse-shoe form; the circular part 20 feet diameter, and the depth from front to back 19 feet, it is about 18 inches thick, batters about 6 inches, and the space between it and the brick-work of the kiln is filled in with rubbish. At the back of the kiln and 3 feet 6 inches above the grate bars, a doorway is made 6 feet 6 inches high, and 4 feet 8 inches wide, arched over with a single brick-arch, through which the kiln is filled. On the opposite side to this opening are two furnace doors, the grates 1 feet 6 inches wide, extending to the back of the kiln. The furnace mouths are funnel-shaped, and are 3 feet 6 inches high above the grates in the inside, this construction making it convenient for turning the rough arches of the limestone when filling the kiln. A shed is built on this side to protect the workmen and the fuel from the weather. In charging the kiln, brushwood is laid over the grates, with a stratum of coals upon it, to form the fire. Large lumps of limestone are then brought in at the doorway, and a rough arch about 3 feet high and 2 feet wide, so firmly built over each grate, that the superincumbent weight of stone may not crush them; the lumps are generally trimmed to shape that they may bed properly, upon these arches the general mass of stone to be burnt is then thrown, care being taken to keep the largest lumps at the bottom, and where the greatest heat will be, and gradually to diminish the size towards the top where the smallest pieces are placed. The top of the charge is about on a level with the surrounding rubble wall. Some care is taken to leave the interstices between the lumps of stone as large as possible, by placing the angles in contact: the object of this is to facilitate the calcination of the large lumps, for if the smaller pieces were mixed with the larger they would be overburnt before the latter were nearly calcined; there is a greater draught also when the spaces between the stones are greater, and this likewise assists to burn the large lumps as quickly as the small. When compact limestone is to be burnt, it should be broken into pieces not exceeding a fist in size. Chalk lumps may be much larger. If the stones are broken into too small pieces, the spaces between them will not give free enough passage to the [illegible]d flame. The stone thrown into the kiln should not be too dry, its state as just taken from the quarry is the best; if it has lost much of its natural moisture from lying by, water should be sprinkled over it with a rose. The reason of moisture being useful is, that the vapour from it facilitates the disengagement of the carbonic acid gas, by reason of its great affinity for water; the stones however must not be wet, only moist.

In commencing the operation of burning, the fire must be slowly lighted, and the heat of the kiln very gradually raised, from 15 to 20 hours being suffered to elapse before the whole intensity of the fuel and draught is allowed to be felt. To keep the fire down, as little air as possible must be allowed to pass through the grate bars; and if there are no shutters or dampers to the ash-pits, lumps of stone may be built up before them, to be gradually removed as greater draught is required. The effect of raising the heat too suddenly would be to destroy the rough arches over the grates, when the mass above them would fall and smother the fire; also the lumps of stone would splinter, and the splinters filling the air spaces between them would destroy the draught. This attention to the gentle increase of the heat is more especially necessary in a new kiln, when the sudden heat would burst the green work; hooping the kiln with iron, to prevent this kind of danger, is therefore to be practised.

84. For burning with wood, in the kiln for that purpose (figure 3,) a temporary dome is first formed of large pieces (slightly trimmed for the purpose) of the material composing the charge,[*] having interstices to admit the passage of the flame, that the necessary degree of heat may be carried to the surfaces of all the material. The larger pieces of stone are placed near the bottom and centre of the kiln, and the others equally distributed according to their size, the smallest being at the summit. Care should be taken to leave interstices as great as possible throughout, by placing the angular parts in contact. The object of this arrangement has been before explained. A slow fire is first kindled with

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[*] Should the nature of the material not admit of its bearing the pressure to which a single vault is subjected, two may be formed, by a pier in the middle; and should this be insufficient, the first course of the intrados of the vault may be composed of incombustible stone, or refractory brick, leaving the openings as directed, in which case the arch may be below. For soft limestone and kunkur, the pieces to form the vault, may be about 10″ × 8″ × 6″ for harder kind somewhat less. If the kiln cannot be conveniently loaded from the top, an opening may be made in the side above the centre for that purpose, which must be closed during the burning.

shavings under the dome, which is gradually increased as the draught gains force, keeping the intensity subdued for about 12 hours or perhaps more, according to the sizes of the kiln, the fire is fed so as to produce the greatest quantity of smoky vapour, that the mass may acquire accession of temperature before the full flare is applied. When that is accomplished, adjust the aperture at the eye of the kiln and keep it constantly supplied with fuel. The air necessary for combustion can be supplied through an aperture in the door, or in the hearth. Where there is no door, after each addition to the fire, the mouth must be partially closed with clay or bricks to increase the draught. But a small quantity of fuel will be consumed the first day, but nearly five times the quantity on the second, the temperature must then be preserved equally, by gradually reducing the combustible on the third, fourth and fifth days, when the kiln is allowed to cool 24 hours before the lime is drawn.* Practice only can determine the proper time for calcination which varies with circumstances, the wood being more or less green, the direction of the wind, nature of the limestone, &c.

In burning with wood it may happen that lumps remain unburnt, in such case it will be advisable to keep up the calcination longer, and have a less intense heat. The mass will generally settle to about ⅕th of the whole and the flame appear of a white color, when the stone is sufficiently burnt; a good test has however been before mentioned.

If required to be kept for any length of time, the kiln should be allowed to cool, close shut, top and all, as the lime becomes more compact and less liable to slake by exposure to the atmosphere. If to be reserved and transported to long distances, it should be put into air-tight casks. In flame kilns, such as described for burning with wood, if, of from 17 to 20 feet high, it is very difficult so to regulate the calcination of the upper parts that the lower strata shall not be overburnt, this is not of much consequence with the poorer lines, but involves considerable loss in the case of the fine hydraulic.

85. *Kilns for burning with Coal, Charcoal, &c.* should, if practicable, be built against a natural bank or rise to facilitate access to the upper parts, otherwise steps must be formed. A shed should likewise be erected close at hand for breaking up the raw material, to keep up a constant supply in

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* In kilns of from 210 to 260 cubic feet the fire will last from 100 to 150 hours.

the kiln, which is not the case with the former ones, a man besides is required in constant attendance day and night as long as a supply is required, as neglect will subject the charge to spoil and much difficulty will be experienced in re-kindling. Argillaceous limestones when burnt with charcoal in contact do not yield so good a hydraulic lime as when burnt with coal, and coal in its turn does not produce so good a result as the blaze of wood and such like fuel.* In coal kilns by slow heat, the stone and coal are mixed, and this method may be considered as slightly precarious, requiring cautious investigation and habit. A kiln may work well for weeks together, and then without apparent cause get out of order. A mere change in the intensity of wind, too great inequality in the fragments, and such like chances, may occasion irregular movements in the descent of the material and irregular calcination will follow. The kiln shown in figures 4, 5, is an approved shape for the combustion of coal as fuel. On the top of the hollow cylinder *B* are laid wrought iron bars 1″ square and 1″ apart which rest on the stouter bars across the openings *d d*, and project about 1½ feet or into the circular opening *A*, to enable one or more to be removed when the charge is being drawn. The space *B* likewise admits air to the combustible; *A* the circular space into which the lime falls when drawn, to which it is directed by a core constructed for that purpose within *B*. If too much draught is caused by both openings *d d*, either may be closed and the core filled up so as to direct the fall of the charge to the other, as shewn by the dotted line. *C*, *C*, are entrances to the circular space. A fire of shavings and small coal is first lighted on the bars, and when alight, the limestone is laid on it about 9″ or 10″ deep, after a little time more coal, and if it burn well, complete the charge by alternate layers of coal and stone, generally in the proportion of from 8″ to 11″ of stone (according to the hardness) to 1″ of coal. The coal should be very small, and with soft material, merely occupies the interstices between the stone. It should be allowed to burn till calcination takes place, which will be at the end of from two to three days (the test is given before); after the first time the kiln should be drawn every 24 hours and by supplying more material as before at the top, it may be kept burning for any length of time. The drawing is effected by removing one or more bars, and if the lime will not fall it must be poked with an iron rod slightly hooked. As strong gusts of wind affect the draught and may spoil the regularity of the burning, it may be necessary to erect a clay screen or enclosure round the openings, at some little distance.

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* This remark is the result of experiment, wherein it was ascertained that charcoal deprived hydraulic lime of one-half the energy it would have acquired if burnt with a flame heat, proving also that the contact of air, exercises useful influence in the calcination.

86. A temporary kind of kiln termed a "field kiln," is sometimes resorted to, for works consuming a large quantity of lime in a short time, the construction is expeditious and economical, but precarious. The lower part is a vault about 10 or 12 feet inner diameter, constructed on the ground, with either large fragments of the charge or mostly with bricks, leaving openings for the flame to rise through, above this is raised a pile of limestone about 15 feet arranged as before mentioned, and enclosed by a curtain of rammed earth supported by coarse wattling, in which is an entrance to the vault.

87. Slaking of lime should be performed as soon after it leaves the kiln as possible, as all limes, and the hydraulic in particular, are difficult to slake after being acted on by the air. The lime should be slaked by just as much water as will reduce the whole to a stiff paste. Too much water is often used and the mass is thereby reduced to a fine paste, but its binding qualities are deteriorated in consequence. In slaking, the hydraulic properties of lime will be conspicuous, as they scarcely give more than one and a quarter volume for one, whereas the poor limes brought to a pulp, are often more than doubled in volume.

For lime of great fineness, such as for whitewash, a sufficient quantity of water should be ready at first, to avoid replenishing at the moment of effervescence. The water should be insensibly applied round the lumps which will suck it up spontaneously.

Slaking by immersion is another method, where the quick lime is plunged into water for a few seconds and withdrawn before it begins to slake, hisses, splits, and falls to powder. It may be kept a long while in this state if sheltered from moisture. Spontaneous slaking by the action of the atmosphere from exposure, has the least effect in bringing out the good qualities of limes, and consequently, less approved of than the others, the ordinary mode is the best.

For slaking by the ordinary process the lumps of lime are spread out in troughs, in layers about 9″ or 10″ deep, the water is poured on gradually, and so that it may spread and penetrate all the spaces. Lime and water are then added

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* Vicat on mortars and cements, page 26.

alternately when the effervescence begins, care being taken not to bring them to a pulp by too much water. If any parts slake to dryness, water should be turned to them by little channels drawn through the pastey mass. A stick should every now and then be stuck into the parts, which, if it come out covered with an adhesive coating, the slaking is proper, if a floury smoke escape, the lime is too dry.*

With eminently hydraulic limes, after slaking and separation of unburnt parts, it will be advantageous to reduce to powder by bruising minute lumps, as this may sometimes develop hidden hydraulic or cement properties. No more lime should be slaked at once than is required for one or two days' work.

The day after slaking the lime is very stiff and to all appearance requiring more water to make it into paste. Not so however, heavy rammers of iron with wooden handles, will soon make it fit and thin enough to be mixed with the other ingredients to form mortar. In the hot weather however it may be necessary to add a little water, but the quantity required will be but small and should be added carefully.

Hydraulic limes would harden if slaked to a paste and allowed to stand any time, they should be therefore slaked with merely water enough to reduce them to a fine powder, about ¼ or ⅓rd the bulk of the lime will be enough if carefully poured over.†

When lime has been slaked to a powder and mixed with the sand, it should be skreened, a skreen for the purpose of about 6 × 8 feet is the best, formed of wires placed ⅜″ apart, and set up at an angle of 45°, all that passes through is fit for use, whilst the remainder will be either stones from the sand, or unslaked lumps of lime, and should be rejected.

88. Mixing the ingredients for mortar should always be performed under cover, and the greatest care be bestowed in working up the mass, as upon this depends the success of the work, and all former labour is lost if this be not carefully done. Smeaton made a constant practice of beating the mortar well with iron pestles perpendicularly, till the mass assumed a tough homogeneous consistency, and he states it to be indispensable; if mixed and beaten the day before using, the process should be repeated on the day it is made over to the bricklayer.

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* Vicat, calcareous, page 22.

† Too much care cannot be observed in pouring the water, as it is surprising how little in excess will drown the lime.

If the lime has been slaked to powder, and cement is to be mixed with it for very fine work, they should be in a minute state of division before mixed, and sand added. If the lime from being overburnt remains for some time in lumps and will not properly slake, as has been before stated to be sometimes the case with hydraulic limes, the lime should be ground in an ordinary mortar mill from 20 to 25 feet diameter, the section of the trough of which is trapezoidal 18″ or 20″ wide at top and 12″ deep ; the sides and bottom of stone or hard brick on good foundation (plate 1, figure 13). The grinding is effected by stone-rollers of the form of a frustum of a cone, in width about a foot, or a heavy wooden wheel may be used with iron tire. A stone or wheel may be placed at each end of the axle if necessary, sufficient water should be added to form a paste, not too thin, and the sand and cement gradually added till the mortar does not adhere to the sides of the trough.

When the lime has been slaked to a fine ductile paste, or reduced to that state by the mill just mentioned, and the cement to be added has been finely ground, the pug-mill is used to mix the ingredients; they are first slightly mixed in a moist state, then thoroughly incorporated by the arms of the axle. When taken out it should be worked over and over with a large hoe or fowrah and brought to the proper temper for use, keeping in mind that stiff mortar is the proper material to form good brick-work with, and that to use it properly, the bricks must be thoroughly soaked without ceasing for a day before using and up to the moment of applying them.

89. Masonry built in the hot season should be watered constantly, so as not to allow the mortar to whiten, as it will not properly harden if dried too suddenly. From the above is shown that durable masonry even in the air will not be obtained from fat limes and sand only, use must be made of hydraulic mortar if permanency is to be desired. Where good natural hydraulic lime is to be had, no other should be used for any purpose. Where no hydraulic lime is obtainable, it will be necessary to make use of fat lime, sand, and hydraulic puzzolana (para. 77). To combine economy and solidity as much as possible, the proportions, in cases where there are to be one part of fat lime and two of sand and puzzolana, the mixture may be made of one part of fat lime measured in paste, one and a half of sand, and a half of hydraulic puzzolana. In works demanding more care, the mortar should be lime, sand, and puzzolana, in equal parts.

90. The strength of mortars as regards tenacity, may be determined by measuring the force required to separate bricks, that having been joined by the mortar, are left for the desired length of time in some place safe from accident. The bricks to be joined in pairs, crossed at right angles thus,

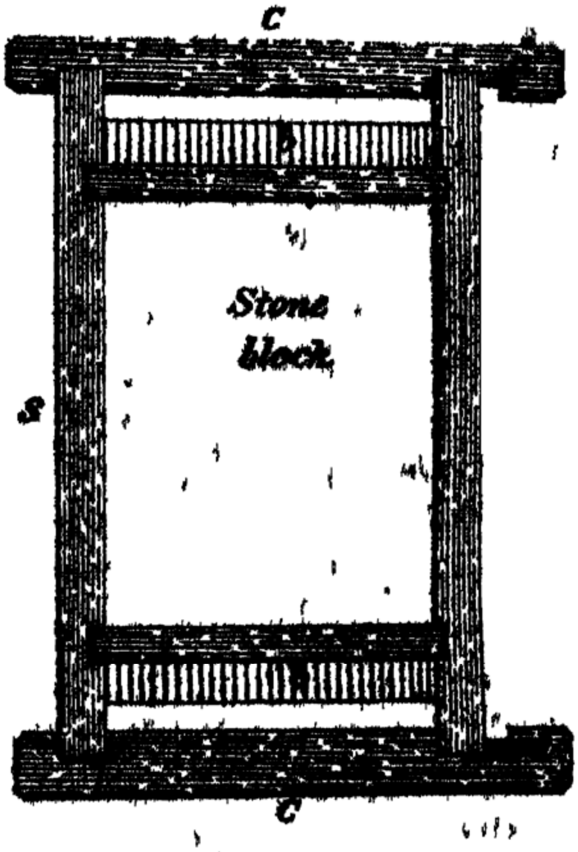
so that supposing each brick to be six inches wide, the surface of contact would be 36 square inches. The real surface, or surface of effectual contact, in every case to be found by actual measurement. The mortar joint separating the bricks to be about ⅜th of an inch thick: and, in order that this mortar should in all cases be equally consolidated, each pair of bricks is to be submitted to the pressure of 600 lbs. for five minutes, immediately after being joined, the mode of separating the bricks may be got from (figure 9, plate 3,) where *a* and *b* represent two strong half-staples fastened to the floor: under these the ends of the lower brick are passed, while the ends of the upper brick are embraced by the piece of iron *c c*, suspended from the steel yard *d*. The force needed to separate the bricks, is applied by pouring sand, at a uniform rate, into the bucket *e*. The weight of the sand and bucket, the mark on the beam where the weight was applied, and the weight of the poise, enable us to ascertain the force necessary to tear the bricks asunder.

91. The following Table of the mean of the analysis of several kinds of kunkur in the Central Provinces will show the consideration necessary for determining the kind and proportion of the ingredients to be mixed with kunkur lime for the purposes of mortar and plaster. The silicates are principally those of clay :—

	From neighbourhood of Cawnpore.	From neighbourhood of Chunar.	From neighbourhood of Allahabad.
Carbonate of lime, ...	63·1	55·3	51·2
Clay, pure, ...	3·9	3·6	5·9
Silicates of clay, &c.,	26·5	35·1	36·1
Oxide of iron, ...	3·4	3·2	4·
Magnesia, ...	2·1	1·9	2·1
From 100 grains, ...	98·5	100·0	99·3

The proportions are regulated as for concrete, the workmen generally use a barrowful of fine gravel and sand to two small shovels-full of sifted quicklime powder, or two measures of the former to one of the latter, for mixing which they use a small pailful of boiling water.[*]

The moulds used are cubical for plain purposes such as walling, but compound ones may be used for mouldings, capitals of columns, &c., and by being forced into moulds adapted to the purpose, successful results have been obtained. Moulds for plain walling stones are constructed, as in the margin, proportioned to the size of the stones required. *S, S,* side pieces with grooves cut to receive the ends, which are loosely fitted to allow of expansion, as the material is worked wet. The parts are held together by clamps *C, C,* which may be wood or iron and tightened by wedges *a, a;* temporary bottoms of board, the ends of which are shown at *b, b,* support the stones whilst making.



For stones of large size a couple of hard wooden trenails should pass through both sides of the moulds near the ends, which are withdrawn in taking the mould to pieces, and leave two holes in the block, which serve for hoisting them into their places on the walls.

The mixture on being thrown into the mould is rammed as it rises, till quite full, when a smooth surface is made with a float. In casting mouldings and stones for fine work, the external faces should be dressed and finished by a plasterer as they leave the mould.

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[*] General Pasley remarks that he doubts the benefit derived from hot water being proportionate to the extra expense of heating it, as cold water is also effectual.

The boiling water is the most proper when the lime is [illegible], as it causes it immediately to slake, and enables you to work with [illegible] moulds.

Stones of small dimensions should be left under cover, at least two months before using, to enable them to harden and dry properly. Large blocks will require a longer time.

Works of great elegance and closely resembling stone buildings may thus be constructed, and doubtless as economically in India as they are elsewhere, as external plastering is avoided; but on no account should they be used till the fullest degree of hardness has been attained, and it need not be added that great care should be bestowed on the ingredients, as failures from want of sufficient attention and good materials will produce disappointment and bring into disrepute any article that otherwise would be really valuable, and particularly in parts of the country where building stone is not procurable.

CHAPTER V.

IRON.

95. Iron is one of the most abundant mineral products of nature, but scarcely ever met with in the proper metallic state in which it is used.

Iron when exposed to humid air becomes rusty, or in chemical language, attracts oxygen* from the atmosphere, an oxide of iron being formed on its surface, and iron has so strong an affinity for oxygen, that it is a difficult matter to prevent this oxidation from going on. This at once shows why native metallic iron is so scarce, and why most of the ores of that metal are oxides.

The oxides of iron seldom present a metallic appearance, and vary in color from bright-red to reddish yellow, though occasionally are nearly black. This metal is so generally disseminated over the surface of the globe, that these oxides give a tint to the whole soil of a district, rendering it brown, red, or yellowish. In these cases the quantity of iron is so small as to render its obtention for useful purposes impossible. Iron mines are immense collections of the metallic ore in masses, stratified nearly horizontally, and often from six to twelve feet thick. The formations of the ore are very common, particularly in mountainous countries, but it is useless without the proximity of a plentiful supply of fuel, and also of limestone to be used as a flux, or means whereby the flowing of the metal is promoted, when produced from its original matrix; those mines therefore alone are worked in which the iron ore, limestone, and either coal or wood, are found in the same locality, which is not an uncommon occurrence.

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* Oxygen is an invisible elastic gas, without color, taste or smell, its specific gravity as compared with air, as 1·111 to 1·000. At mean temperature 100 cubic inches of oxygen weigh 34·60 grains. It forms $\frac{1}{3}$rd the weight of the atmosphere, $\frac{8}{9}$ths of the weight of water.

96. The working of iron mines, that is, the art of extracting the ore, building and working the furnaces for the reduction and purification of the metal, the machinery for its manufacture into bars and rods, are not likely to fall within the practice of the Engineer in India,* more particularly as the ready prepared material is exported in such abundance and at such moderate prices from England, but it is necessary to put him in possession of such information as shall enable him to judge of the qualities of the metal which may be presented to him under different forms, and to use it to the best advantage, both in "pig" and its malleable state.†

Iron has a strong affinity for almost all the natural combustibles, and readily mixes with most other metals, forming alloys that essentially alter the character of the metal. A combination made artificially of sulphur and iron at a white heat cannot be dissolved by any means, and the iron is spoiled for all useful purposes, as the compound possesses no quality that renders iron valuable. It is often found naturally combined with sulphur, forming a beautiful mineral chrystalline with bright metallic lustre, and by the ignorant might be, and has been, mistaken for gold. This mineral requires to be carefully extracted from the iron ore before working, as a little of it will deteriorate a large quantity of iron.

Carbon, or the pure material of coal; unites with iron in the same manner as sulphur, though to a less extent and is less injurious; the reduction of iron ore consists in filling the furnaces with alternate layers of ore, limestones and fuel, which soon gets into a state of ignition by the aid of the powerful blast employed; being thus deprived of its oxygen, and trickling down through the ignited fuel, it comes into contact with carbon whilst both are at a high temperature, and a union takes place. In this manner all iron is reduced in the first instance, the bottom of the furnace being tapped, the fluid metal flows out, and when cold assumes the character of metallic iron, but in this state it is unfit for general use, being very brittle and so hard that no file will touch it.

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* A probability greater than when this was first penned, for no better iron exists on the globe than Indian, which wants but British capital and enterprise.

† Since the above was written enquiries of a valuable nature have been made relative to the advantages of working Indian iron mines by European Agency, and the author doubts not that good results would ensue therefrom.

The appearance of its fracture is white and crystalline, its denomination is "crude iron," and it may be run into heavy castings, that require no subsequent turning, drilling, or any operation of a tool. It is thus evident that the fuel used for the reduction of the iron has a considerable influence on it; most kinds of coal contain sulphur, which is so prejudicial to iron as to prohibit the use of it in smelting the ore. Wood contains nothing that can injure iron, but in its ordinary state its humidity prevents rapid combustion, and it will not yield heat enough till converted into charcoal, it is then the best fuel that can be used, but expensive on account of the rapidity of its burning and the labour of preparing it. "Swedish iron" owes its celebrity for toughness and ductility to its manufacture from the charcoal of pine wood; next to charcoal "coke," which is the cinder of bituminous coal, is the best material for reducing iron ore, and is that most commonly used.

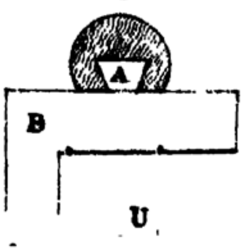
97. Coke is pit-coal, broken into small pieces, ignited with free access of air, and permitted to burn till it ceases to give out flame or smoke, and the whole mass is become red-hot. It is then shut up to the total exclusion of air, when combustion is suspended, and in this state, when cool, is fit for use. It is better made in a close oven than in any other way, yet such ovens are tedious to build and expensive, so that coke is generally made on the ground. The coal is piled up in long heaps, and after being ignited and allowed to burn a sufficient time, earth is dug and thrown upon it till the air is quite shut out, the heaps are then watered through the earth, and not opened till quite cold.

The following description of the mode of smelting iron by the Indian method, is partly from observation partly from a little work by A. Aikin, Esq., F.R.S., F.G.S.

98. All Indian furnaces are on the same general construction, differing only in size and in the relative proportions of some of the parts. I shall therefore describe in detail sufficient for my present purpose, those which are used in Central India.

In the annexed ground-plan, (fig. 1,) *B* is a trench three feet deep having a sloping entrance, and *A* is the furnace, the shaded part showing the comparative thickness of the walls which are made of large unburnt bricks and lined with clay.

Fig. 1.



In (figures 2 and 3) are represented a front elevation and section of the furnace. The first thing that strikes the eye is the obliquity of the furnace as seen in (figure 3), which is an essential condition in its construction. C is a large block of sandstone or some other hard and difficult fusible rock: its surface slopes towards the front in order to direct the melted matter to the perforated earthen plate *D*, the holes in which are opened from time to time with an iron bar in order to let out the melted slag or scoriæ; *E* is the tuyère or blast-pipe, composed of two diverging earthen tubes inserted into a mass of dried clay: (figure 2) shows a front view of the part, (figure 3) a section, and (figure 4) a plan of the same; this latter likewise shows how large a proportion it occupies of the area of the furnace at the place where it is inserted.

Fig. 2.

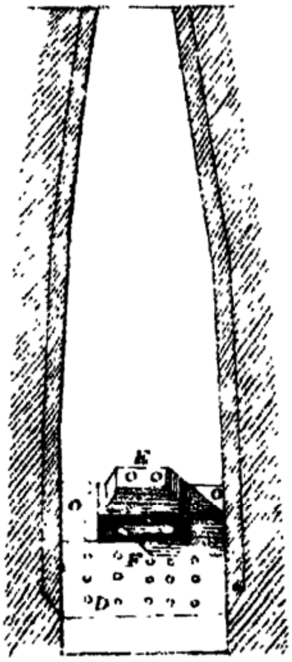
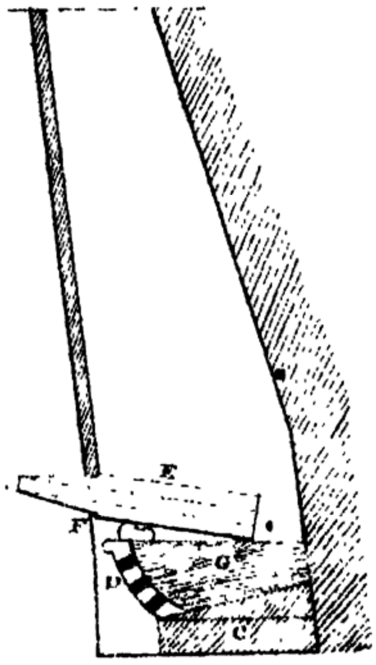
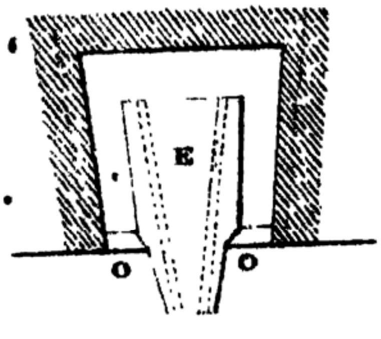


Fig. 3.



F, (figures 2 and 3) is a wedge of clay on which the tuyère rest and by which its angular position is adjusted, while the end of the tuyère rests on *G*, a mass of cow-dung and chaff with which the bottom of the furnace is filled previous to smelting. *O O*, (figure 4) are plates of burnt clay or thick tiles that fill up the space in front of the furnace not occupied by the tuyère.

Fig. 4.



The bellows are made of skin and are two in number, and a pipe projecting from the bottom of each is united with the blast-pipes of the tuyère. These bellows are placed on a plank laid across the trench in front of the furnace, at the further end of which is seated a man, who by working the bellows alternately one by the right and the other by the left hand, produces a continued stream of wind. The entire height of the furnace varies from 4 feet 4 inches to 8 feet, and its diameter at the widest part from 1 foot, to 3 feet 9 inches.

99. The fuel is universally charcoal, that from the bamboo being by long experience greatly preferred to any other. No lime or other flux of any kind is employed. It is easy to see why, in the absence of flux, bamboo charcoal always gives the best results.

Bamboo is nothing more than a gigantic grass, and like the smaller grasses and corns of our own country, is covered externally with a hard glossy varnish, this varnish is silica; it likewise, in common with all other land plants, contains potash, and as it is very possible by a dexterous application of the blow-pipe to burn off the combustible matter of a piece of wheat straw and melt the residual silica and fixed alkali into a drop of glass, so probably the same thing would occur with a twig of bamboo, this kind of charcoal therefore may be considered as furnishing not only fuel but a very active and excellent flux. The minor details of the process vary in different works, but they all agree in charcoal only being put into the furnace at first, in order to bring it up to a proper heat, and then in the ore and fuel being added alternately to the end of the operation, the proportion of fuel to ore being two measures of the former to one of the latter in Central India, where they smelt a fusible hydrate and obtain an excellent steely iron.

At the end of from 6 to 12 hours, according to the size of the furnace, the tuyère is for the most part melted and is no longer serviceable; this first part of the process is therefore necessarily finished, and on breaking down the front of the furnace there is found a mass of crude iron weighing from 24 to 100lbs., which is drawn out by strong tongs while still hot and is divided by a hammer and chisel into two nearly equal blocks. This crude iron is of a greyish-white color, is very porous, the cavities being filled with charcoal and slag, is sometimes quite brittle but generally malleable in a slight degree, and if, during the last four hours of the furnace being in activity, no ore, but only charcoal has been added, is found sufficiently malleable for common uses after being merely drawn down by the hammer into small bars. This crude metal has never been in a state of actual fusion; the Indian furnaces from their small size, from their thinness which allows a rapid escape of the heat, and from the comparatively inefficacious hand bellows made use of, not being capable of receiving or retaining a sufficient intensity of heat to produce this effect.

The block of crude iron is laid, covered with charcoal, on the ledge of the chimney, with one end projecting a little just above the mouth of the tuyère. In this situation the end of the block soon softens and then falls down in a state of half fusion; a man with an iron bar then draws the remainder of the block a little forwards, advancing it from time to time till the whole has sunk to the bottom of the furnace. It is now dragged out while glowing hot and hammered on an anvil to separate most of the scoriæ, is then subdivided into two or three pieces, heated and again hammered, and this process is repeated till the iron is quite malleable.

From the above slight, though preliminarily necessary sketch of the manner of producing iron, it is apparent that it is obtained in a fluid state in the first instance, yet it is met with in two distinct forms, "malleable or wrought-iron" and "cast-iron," the characters of which are as distinct as two separate metals.

MALLEABLE OR WROUGHT-IRON.

100. Malleable or wrought-iron is manufactured into rectangular pieces or "bars," cylindrical pieces or "rods," and flat plates or "sheets," and if good, should be characterized by its toughness, ductility, capability of bending, also by its strength, capability of receiving and retaining a high polish, its fibrous texture, the facility with which it rusts, its capability of being welded, (one of its most valuable properties) which is the firm union of two pieces by hammering when at a high heat, and its resistance to fusion by heat; for malleable iron may be wholly converted into oxide when too highly heated and will burn, but will not admit of fusion. It is generally admitted that by a judicious disposition of metal in the sectional area of a bar of iron, greater strength may be obtained with a given weight, than with a larger amount of metal injudici-

ously disposed, it was thus after many experiments, that the T;][, and L iron had their origin, the former being exceedingly useful as rafters, girders, floor joists, &c., the][for similar purposes where greater strength is required, and the L iron as battens, and means of strengthening the angles of boilers, tanks, tubular beams, &c., they all possess great strength with ecomony of metal, and are formed in rolling mills like other bars. Their application and utility will be treated of in Part II. in the Chapter on "Iron Roofing." Hence the application of "wrought-iron" to all purposes, parts of machines, or framing for roofs and bridges as are subject to tension or torsion, whilst on the contrary "cast-iron" is employed where resistance to a crushing force or to compression is required. It has no ductility but little toughness, and will bend but very slightly without breaking. It is inferior in actual strength to malleable iron, may be made smooth and polished, but will not attain a reflective surface, has a granular instead of a fibrous texture, rusts slowly, cannot be united by welding, fuses and becomes liquid when exposed to a high heat.

The iron in both cases is the same, and these differences of character depend on the quantities of carbon and oxygen that have combined with the metal, at the time of its reduction. Iron in its malleable state is supposed to be pure and free from alloy, but cast-iron is alloyed with carbon and oxygen, and the proportions of these elements that are present, affect the quality of the metal, it is therefore a carburet of iron combined with oxygen.

101. The process therefore, of procuring malleable iron, is to refine or purify the imperfect carburet of iron that is obtained from the ore by the first process of reduction as above described, by taking from it the carbon it had imbibed; and this is done by melting the crude or forge-iron a second time in a reverberating furnace, or one so constructed, that the iron shall be exposed to a free current of air, and shall be subject to all the heat of the fuel, without being in contact with it. So soon as the iron is fused, it is kept constantly stirred and moved about by iron rods, so as to constantly expose new surfaces to the heat and air, which process is called puddling, and by which any carbonaceous matter the iron contained is burnt and consumed, and other portions of iron combine with the oxygen of the air; in consequence of which changes, the iron shortly loses its fluidity and becomes ropy and tenacious like dough, and the workman, judging from his experience when this change has been sufficiently

wrought, removes the mass of iron from the furnace, and places it on a large anvil where it receives a few blows from a very heavy forge hammer worked by machinery, and which forms it into the shape of a square bar of from two or three feet in length. The blows of this hammer not only form the bar, but they render the mass more dense and compact, and drive off all the oxide of iron that was formed during the puddling process; this flies off in all directions under the hammer, forming scintillating sparks of great brilliancy and beauty. The short bar while yet in a glowing heat is speedily carried to the forming rollers of which figure 1, plate 4 is a representation, if a square bar is desired, it is presented into the square opening *d*, and is carried forward by the revolution of the two cast-iron rollers *b* and *c*. If a smaller bar is required, the hot piece is returned back again through the next opening *e*, and afterwards through *f*, and so on, until it is reduced to the required size. If a round rod of iron is required, then the piece is in like manner presented to and passed through the round openings *g h*, &c., and thus the hot bar which was originally only 30 inches in length, is extended to 10 or 12 feet, or even more, and is afterwards cut by the shears to the required length of the bar. All bars of iron are now formed by passing them between rollers of this kind, and of course iron mills must possess a number of such rollers suited to the sizes and forms of the iron to be produced, because, by altering the indentations in the rollers, bar iron of any form may be produced.

To compensate for the imperfect operation of the rollers, every bar that passes through them should be reduced to a small size, and be then cut and doubled, a welding heat should then be applied to the two bars, when they are again to be passed through the rollers to be consolidated into a single bar, and reduced to the required size. When two or more bars are heated, placed together, and welded into a single bar by the action of rollers or hammers, the process is called "faggotting," and the strength of the iron is much increased thereby.

When wrought-iron is really good, it ought to bear bending even in a cold state, without breaking, and the fracture when broken, should exhibit a decidedly fibrous character; when bad or brittle, it will not bear bending when cold, and the fracture is lustrous and granular.

102. "Scrap" iron derives its name from being formed of all the waste scraps and bits of iron cut from bars or bolt iron, or produced in working them,

as well as from all old iron saved. It is very much approved for purposes where great strength is required, such as nuts, eyes of links of chain bars, or eyes of all rods, subjected to tension; the iron being originally in small pieces, is packed in all directions, and thoroughly incorporated by either rollers, tilt, or forge hammers, and thus the fibres, being interlaced, the iron produced is more tough and strong than any other kind.

103. Wrought-iron work is carried on by two distinct sets of workmen, the blacksmith or forgeman, and the whitesmith or fileman; there used to be in all large and in many small establishments a third workman called the bellowsman, who is also a forgeman or hammerman, when not urging the bellows; but since the introduction of the fan blast into large workshops the third man has been dispensed with, and each forge has two forgemen attached; the most expert of the two seeing to the due heat being given to the iron, regulating the blast, and when the iron is ready, fashioning it with his hammer assisted by the other. The introduction of the fan for giving blast to forges is one of the most useful additions that science has given to the blacksmith's shop, for independent of the power of its range enabling it to supply the blast to 70 or 80 forges, its force can be regulated to a nicety by the movement of the elliptical aperture in the cock attached to the funnel of each forge, and a welding heat is more rapidly and certainly attained than by the mere aid of the bellows, which, if carelessly worked, was, and is often the cause of false welds, inferior faggotting, delay, and extra expense. Figure 2, plate 4, shows the apparatus which consists of four or sometimes five fans attached to arms set at a certain angle on their axle, and enclosed in a drum, the space between the edges of the fans and inner surface of the drum being a spiral tube, through the end of which prolonged, the blast is driven; a pully is attached to the axle to receive a strap from the gearing connected with a steam engine.

104. The smith's anvil has a beak for forming round or curved work on, and it has a square hole at the other end for putting iron over that has to be punched, and for holding the shanks of what are called "bottom tools"* that

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* The names of the tools and appliances are here given as referring to in English smithery, for as yet iron working in any place except Calcutta, may be considered but in its infancy, the value of the machines, mechanical and other tools in common use in Europe, not being known to Natives, though their introduction into the establishment at Roorkhee and Futtehgur, is proof of their appreciation, and will doubtless tend to their more general use.

fit on to the anvil, for if a piece of iron has to be rounded or made into the form of a moulding, the bottom tool is inserted in the hole in the anvil, the heated iron laid upon it, and the top tool held by its handle placed over and struck by the sledge hammer, till the necessary form is given to the iron.

Holes are expeditiously made by punches, which are slightly tapering tools of steel of various sizes, with blunt ends, driven through the hot iron laid over the hole in the anvil for the purpose.

105. Maundrells are generally cylindrical tools introduced into holes after they have been punched, to render them true and of a certain size, which is the more necessary when female screws have to be cut in the holes. There are besides maundrells of other forms.

106. One of the most frequent operations of the blacksmith is welding or joining two pieces of iron together; the facility with which this is done adds much to the value of wrought-iron. The heads of bolts are put on by forming a collar of square iron, which is fitted to the end of the bolt, they are then both brought to a white heat and welded at a single process. Small bolts are headed by a rivetting process, the piece of iron being driven into a square or round hole in a block of iron called a "swage." The hole should be rather smaller than the hot iron which is driven in by the hammer, which by the compression used, forms a head to the piece, which is at the same time truly adjusted to the swage hole, and is easily withdrawn as it contracts when cool.

107. The swage block is the fellow tool to the maundrell, the former giving a determinate size to the bolt, and the latter to the hole that the bolt is to fit into, when screwed or otherwise finished.

108. "Faggotting" is the process of welding several pieces or bars together to one of more than ordinary strength, as it is safer to trust to such a faggotted bar than to a single one of the same size, more especially as large bars are seldom so compact or well wrought throughout as small ones. Nuts also for screw bolts to be subjected to great strain should be formed in this manner, taking iron of the proper width but one-third the thickness, and doubling or trebling it at a welding heat.

The only thing to be guarded against in this operation is a false weld or faggot, being an imperfect union, owing to either want of due heat, or formation of an oxide on the surfaces to be faggotted; such a defect may exist without being visible from the outside, and is prevented by bringing clean surfaces together, and sprinkling them with dry sand when heated; the sand fuses and vitrifies, thus protecting the surface of the iron from oxidation by forming a thin coat of glass over it, which is driven off from the joint by the first blows of the hammer.

109. "Jumping" is another necessary operation that is performed on the ends of bars previous to their being welded. It is merely making them red-hot, and driving them against the side or top of the anvil, or block of cast-iron fixed in the floor, in order to render the ends thicker than the rest of the bar, because in welding, the two ends have to be well hammered together to produce perfect union, consequently the joined part of the bar would be less in diameter than the rest, if the reduction was not prevented by jumping or previously making the parts to be joined so much larger that the necessary hammering produces a uniform dimension throughout.

110. The fuel of a blacksmith's forge is of great importance, for the best iron may be spoiled by a bad fire, composed of coal containing sulphur, arsenic, lead or any other mineral that will combine with iron at a high heat, and thus destroy its valuable properties, or render it what is technically called "rotten." Wood charcoal is the safest fuel to use in respect to the iron, because it contains nothing that can injure it; but it is troublesome in its management and throws off so many sparks as to render it difficult and disagreeable to work with; independent of which its combustion and consequently consumption is very rapid.

The varieties of pit coal, which are denominated "smithy coal" from their being sought after for forge purposes are excellent kinds, and exported to this country by the Iron Establishments and Mint in Calcutta. It is a small coal generally from Northumberland, and not useful for domestic purposes.

111. All work produced by the blacksmith or forgeman, is said to be forged, and he delivers it in its black unpolished state, hence his name, and the perfection of his work is to forge pieces so neatly, as to bring them very nearly to their intended shape, leaving the fileman little else to do than file away or otherwise remove the black external surface.

The whitesmith or fileman works before a vice, and his tools are cold chisels, saws, files, drills (generally worked by machinery), rimers, screw-cutting apparatus and a lathe.

112. Screws in all large Establishments, are generally cut either in a lathe or regular screw-cutting machine, and no iron works should be without such tools for the sake of the rapidity and accuracy with which the screws are cut; but where such is not the case, or where there may be but one such machine, they are cut by taps and dies, and small screws by a screw plate. The tap is a short circular rod of the best steel, with a square head for turning it by means of a spanner or wrench, it is made slightly tapering, and a perfect screw or thread is cut on its surface when the point and some distance above it is filed away until the tap becomes square, leaving the screw-threads at the four angles. The tap is then tempered and is fit for use. Being conical slightly, the small end is introduced into the nut in which the female screw is to be cut, and by turning it forcibly with the spanner whilst the nut is held in a vice, the required concave thread is obtained. The dies are two small blocks of steel fitted so as to slide close together, or a small distance asunder, in an iron frame, called the stock, which has two long handles. The dies are brought together by a screw passing through one side of the stock. The two sides that face each other are filed out so as to form nearly a circular hole, in the inside of which is cut a screw by the tap, so that the impression of one-half of the screw is in each block or die, and indentations are filed across the threads to produce sharp edges. The bolt to be cut, is fixed vertically in a vice, and the dies are compressed on it, the forcing screw made to pinch tightly, when the stock is turned by the handles, and the screw-thread cut on the bolt.

The ends of all rods to be screwed, that are intended to resist a tensile force, should be made thicker than the rest of the rod, by a quantity equal to twice the depth of the thread; that the sectional area of iron remain unimpaired throughout the entire length.

113. The lathe is of first rate importance to the Engineer and Mechanic, and without its aid the perfection which machinery has reached could never have been obtained, for it affords the only means by which the workman can render his material perfectly round or flat; whilst the addition of the slide rest, in which the cutting tool is held by a firm press worked by fine threaded screws, has rendered the operations with the lathe mathematically correct. The slide rest should therefore be considered as an indispensable part of a lathe. In India, and especially in smitheries and foundries in the North-Western

Provinces, each Establishment should be possessed of the means of repairing and making its own tools, and of repairing and re-placing any parts of either a steam engine or mechanical tool that may go wrong, otherwise work may be brought to a stop. Spheres, cylinders, cones, spheroids, and every figure that has a circle for its base or root can be formed accurately, by the different arrangements of this most useful implement, nor is it confined to wrought-iron work, cast-iron, brass, wood, and every material capable of being turned can be similarly brought under its operation. Lathes are various in their form and application, from dimensions capable of working on pieces of several tons in weight, to the delicate implement upon which the watch-maker forms his finest wheels.

Lathes of any magnitude, or such as are in use in iron works, are generally driven by steam power, and their moving velocity should be made variable by means of reversed conical gearing, as cast-iron requires a very slow motion, and wrought-iron rather a more rapid one, brass a great velocity, whilst wood requires a motion more moderate.

The several processes to which wrought-iron is submitted are included in the above description, excepting only such details as belong solely to the workman.

Those explained are what an Engineer should know the existence of, and one in charge of iron works have a practical acquaintance with, as well as the details connected with

CAST-IRON,

114. Which on account of its hardness, strength, durability, small tendency to oxidation, resistance to heat and cold, and facility with which it may be put into any form, renders it one of the most valuable material that the Engineer has to deal with, and which will be the more appreciated as the foundries at Roorkhee and Futteghur shall be enabled to cast the varieties of articles required of this metal; for the Department Public Works has hitherto been deprived of it owing to the very great distance and expense at which it was to be obtained, though it is most desirable that a material* so important

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* This is equally if not more applicable to wrought-iron in India, as capable of more extended use and more easy of transport.

to resist the agents which principally cause the ruin of the destructible portions of the public buildings in India, should be more generally brought into requisition.

The reduction of crude-iron from its ore, has already been given; Art. (96) which from its being too hard and incapable of flowing freely, is unfit for casting purposes; iron for foundry purposes becomes good in proportion as it receives a higher charge of carbon, consequently an opposite process has to be observed to obtain this iron from that of wrought-iron. It has to be re-melted in close contact with the fuel, and with as little exposure to the air as possible, and it accordingly undergoes this second melting in which it absorbs an additional quantity of carbon, after which it is tapped, and run into foundry "pigs;" the term "pig" iron is common in all countries as applied to the bars which are formed in a series of troughs at right angles from a main trough into which the metal flows first when the furnace is tapped; the larger or main trough being called the "sow," which generally retains the impurities direct from the furnace, and are not communicated to the pigs.

Referring to the important service that the abovementioned foundries in the North-West are likely to render to the Department of Public Works, with which Establishments the Engineers of the Department will be required to correspond, it is necessary that they should be acquainted with the operations therein carried [illegible], and with the manner of making moulds, to prevent the expense that might otherwise be incurred in preparing patterns from which castings cannot be made, or demanding articles of cast-iron that more properly would be executed in wrought.

115. Pig-iron is known under three denominations, Nos. 1, 2 and 3; No. 1, a soft grey kind, is the best; No. 2, medium, and No. 3, very little better than crude-iron. The quality is judged of by the appearance of the fracture, the sound, and by seeing if it indents or breaks from blows of a hammer. Place one pig on the ground, and throw the rest successively over it transversely, and the facility with which it breaks will give a fair criterion of its quality for strength or toughness. The sound of the blow should at the same time be attended to, for the finest soft iron scarcely yields more sound than would a block of lead. Its fracture will be coarsely granular, with no great lustre. No. 3 being very brittle, re-bounds with a metallic sound, has

little or no granular appearance, its fracture of silvery whiteness and strong lustre. No. 2 is, as before said, a medium between the others. The form of the pig should likewise be regarded to see if the underside carries the impression of the little irregularities of the sand in which it has been run, if it does, it is a proof that it will flow freely into the moulds. The three qualities mentioned derive their character from the quantity of carbon they have imbibed at their formation.

116. The iron-founder uses two kinds of furnace for melting his iron, the "cupola" and the "air-furnace;" small foundries should never have less than two cupolas, as repairs are so frequent that one is constantly out of use.

The cupola will only melt properly from one to twelve cwt. of metal at a time, and during the whole of the operation requires to be urged by the fan blast described at Art. (103.)

117. The air-furnace is made large enough to fuse from five to seven tons at once, requires no blowing, but works by a natural current of air induced by a very tall chimney. The operation of the air-furnace is valuable to the founder who works for trade, and has constant and large castings to produce, but the cupola is best adapted to the requirements of our Indian Establishments, where the greater part of the work cast will be under 10 cwt.

118. There are four denominations of castings depending on the manner in which the mould is made. They are open sand-box castings in dry and green sand, and loam castings. The moulds for all but the last being of sand, having peculiar properties, and as yet only procurable from Europe.* It contains a clayey loamy matter that causes it to retain any form given to it when slightly moistened, and must not burn into hardness from the heat of the melted iron.† Open sand-casting is only applicable to flat plates, bars, or such positions where one side only is exposed to view, where strength without beauty is required, and where it is not detrimental to have one side rough. To produce a casting, a pattern is necessary, being a facsimile in wood of the thing to be

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* The search for moulding sand should be eagerly prosecuted as a valuable ingredient, would be rendered available to the Indian founder.

† Since the above was written good sand has been dug from the neighbourhood of Calcutta, rendered fit for moulding purposes by the mixture of a little charcoal. This is now in use at the Iron Bridge Yard.

cast in iron, it is imbedded in the sand which is closely rammed round it, keeping the top of the pattern quite level. When moulded, the pattern is gently withdrawn vertically and may be again used. The disadvantage of open sand-castings is their liability to warp, if of an extended form, and care is not taken to ensure equable cooling. Their upper sides too will present air-bubbles and dross, rendering it rough and unsightly.

When every side of a casting is required to be fair and smooth, the top of the mould must be covered with sand as well as the other parts, and this can only be done by making the mould in a box, that divides into two or more parts according to the intricacy of the article to be formed; such boxes of various forms and sizes are therefore necessary items in the stock of every foundry. All box-castings require a pattern likewise, and if the box is filled with the ordinary damp sand of the foundry without being dried, such sand is called "green," but though green sand is so constantly used for the common work of the foundries in England, it requires the greatest nicety and care in using, and is not the best material, certainly for India, and its unpractised workmen. The sand requires slight moistening that it may retain the form of the pattern, but if green sand be moistened in the smallest degree, too much steam is suddenly generated when the fluid iron is poured in to the mould, which is thus blown up, and the hot metal dispersed in all directions. Even when the mould is safe, the melted iron coming in contact with damp sand and the cold generated by sudden evaporation, produces a bad effect on the iron by rendering it refractory and hard, an advantage, if the lathe or file have not to be employed on it; but all castings that have to be worked on should be cast in "dry" sand. The process for both "green" and "dry" sand-casting is alike, except that as soon as the mould is finished for a dry sand-casting, the box is carried to the store, opened, and kept till dry and hard; after being returned to the foundry, a fire is made round it and over it, heating the sand before the metal is run into it. The box is not opened till the metal is quite cold. This makes castings rather more expensive, but should be adopted till experience enables the workmen to cast in the sand as it is received from England.

119. The boxes are best made of cast-iron, of various forms and sizes, they consist of four plates forming two boxes *F* and *G* of the same dimensions, (plate 4, figure 3,) and are without tops or bottoms, but to prevent the long

sides of large boxes from bulging a sufficient number of braces, *h h* must be fixed across the top of the upper, and side of the lower box. The meeting edges of the boxes should be so even, that a perfect joint be formed and their true position preserved by the steadying pins *m m* passing into holes *l l* on the upper edge of the lower box.

To mould an article of which the pattern has been prepared, the lower box is placed as level as possible and sand rammed into it well to such a height that one-half the thickness of the pattern placed in the box shall be exactly sunk in it, and the other half wholly above its upper edge. The lower box is then filled up level with sand carefully rammed round the pattern, the top of the sand is then made hard and level as possible by a small well-polished trowel. That done, a small quantity of very fine brick-dust is sprinkled over the top to prevent the adhesion of the sand in the two boxes. The upper box is now placed on the lower as in (figure 3,) and well rammed with sand to obtain the impression of the upper half of the pattern. Before filling the top box two slightly tapering turned sticks are placed vertically, small end downwards on the pattern, and rammed about with sand as well as the pattern itself, and when the upper box is filled the moulding is complete. A funnel-shaped cavity is then sunk with the fingers round one of the sticks and they are then withdrawn. The hole that is left with the funnel opening, is called the "gate," and is the channel by which the metal is poured in, the other is the "vent," for the escape of the air, as well as the steam and gas that is generated as soon as the hot iron is introduced; it also informs the moulder when the mould is full, that he may cease pouring. When the moulding as above described is completed, the most difficult and delicate operation remains to be effected, which is that of separating the two boxes for the removal of the pattern, without breaking down the sand in which the impression has been made. In large and heavy castings, or where there are many boxes to lift, the operation is effected by a circular crane with rack and pinion work on the horizontal beam, this crane sweeps the whole area of the moulding shop and can be adjusted to pick up a top box from any point in the area. It is used also to convey the liquid metal from the cupola to the casting boxes, when the ladle in which it is carried is larger than four men can manage. For small work or where there is not much of it, the operation is conducted by a man going to each top handle *ii*, who raises the box as steadily as possible, inverting it most carefully on the floor for examination, and any little repairs the sand may require.

To remove the pattern from the lower box, is not difficult, a little water from a rag is applied all round the pattern, and one or two nails driven into the top whereby to lift it, or by striking it gently with a hammer to loosen it, it may be gently lifted from its bed without any serious damage to the sand.

The most convenient way for an Engineer to transact business with a distant foundry, and one which is attendant with the least probabilities of disappointment or error, is for him to prepare under his own eye the wooden patterns of the articles required to be cast, and to send them to the foundry; for to whatever locality the casting can be sent from the foundry, the pattern can be sent from the former to the latter; elaborate and detailed drawings, though necessary accompaniments to an estimate, necessary also as working plans to a subordinate or overseer, would occasion much loss and trouble if misunderstood by the pattern-makers at the foundry, and might cause a casting to be sent that did not agree with what was wanted. Cast-iron is so hard a material to work in, that every precaution should be taken to guard against having any more work than is absolutely necessary to do to a casting after it leaves the foundry: to prevent therefore an Engineer from making his patterns wrong, and thereby probably receiving a solid when he wanted a hollow casting, he must bear in mind that though a pattern is the exact representation of the thing to be cast, holes and hollows are just the reverse, for instead of making a hole in the pattern where a hole is required in the casting, it should be marked by convex projection of the same size and form as the hole, such projections being called "prints." The print is for the purpose of making an impression of the hole in the sand, which hole is to contain a core made of loam, sand, or other material, the size of which is pointed out by the print hole, which it must exactly fit.

120. The core need form no portion of the care of the Engineer requiring the casting, the prints are his business, which should be put on exactly where holes are wanted, and the moulding foreman at the foundry will understand them, they should be fastened on with brads, never glued, nor should glue be used in any part of a pattern, or however neatly it may have been managed,

the moist heat of the moulding sand will dissolve it more or less and the sand will then adhere to the pattern. Dovetailing and brads must be resorted to.

For the information of the Engineer studying or first joining a foundry, he should learn that cores must be of such material as will resist heat and the pressure of the iron, yet not bake into so hard a substance as shall prevent its removal from the hole when the casting is finished. Long cores particularly when used horizontally, must be strong and incapable of bending, for iron in a fluid state has a buoyant power of more than half that of quicksilver and will float up any thing lighter than itself, such cores therefore are made upon iron bars, if of medium size, or on tubes of cast-iron pierced with small holes, if the hollow required will admit them. The holes are for the discharge of air and steam as the hot metal is poured in, these core tubes being principally required for casting pipes. The core is prepared on the tube by first twisting wet hay round it in an even manner which is afterwards covered with well-beaten wet loam, mixed with hair or cotton, to give it tenacity. It is made truly cylindrical by means of a small winch, which is fixed to one or two iron pivots previously inserted in the ends of the tube, and made to revolve against the straight edge of a board. It is afterwards dried or baked in the "stove" which is a brick room attached to the foundry, with an arched covering, and closed by iron folding doors; good fires are kept in this room, that it may be constantly hot for drying cores and moulds. Cores after they are baked hard, require to be dressed and smoothed by a coarse file; then blackened by a mixture of coal dust and water, and finally dried again for use.

121. Loam-casting is the most difficult and costly, and only resorted to when castings are required for large manufacturing purposes, which a box could not contain, such as the cylinder of a steam engine, air vessels for forcing pumps, &c., &c., they are carried on from drawings principally, and require a powerful circular crane for the operations. The moulding is the same as modelling in clay or loam, the charge of metal for the casting requires to be run from an air-furnace, as in general a cupola could not hold it, and instead of being carried to the mould in ladles, is run in a gutter of sand from the top hole of the furnace to the gate of the mould.

122. Patterns are never made in single pieces when it can be avoided, but in two halves put together with steady-pins, the object of this arrangement

is to diminish the difficulty of taking the pattern out of the moulds, as they are so placed in the boxes that the joining is horizontal, and on separating them one-half the pattern remains in each box. The surfaces of patterns should be very smooth, and the lower part that is to sink into the sand, smaller in a slight degree than the upper, that it may become immediately detached from the sand on being raised in the slightest degree.

Different kinds of iron contract in different degrees in cooling, No. 3 most of all; so that it is of importance in making patterns that an allowance be made for this contraction. The average that is made is one-eighth of an inch to each foot of extension for medium or No. 2, this being rather too much for No. 1 and not quite enough for No. 3.

The weight of castings may be approximately ascertained by weighing the pattern and multiplying that weight by 14·4 if of light wood such as deal, or by 10·8 if of harder wood, such as toon.

123. The specific gravity of cast-iron is 7·207* a cubic foot, weight 450 lbs., and a superficial foot one inch thick, weight 37½ lbs.

124. The fatal consequences that might result from the use of timber for supporting heavy buildings, either in case of fire or of decay, have often been foreseen, but in few instances it has happened that where iron has been used for greater security against fire, the structure has failed from want of strength. Such failures have not occurred from any defect in the material itself; for it too often happens that such works are conducted by persons of little experience and less scientific knowledge. Men of little experience too frequently imagine that a large piece of iron is almost of infinite strength; and they often have a like indistinct notion of pressure. They design to please the eye, without regard to fitness, strength, or durability, instead of ornamenting a support, they make the support itself the ornament, and sacrifice every thing to lightness of effect. The dimensions of the most important parts of structures are too often fixed by guess or chance; and the person who calculates the value of materials to the fraction of a penny, seldom if ever, attempts to estimate their power, or the stress to which they will be exposed.

When it is considered that it is absolutely necessary that the parts of a building or a machine should preserve a certain form or position, as well as that they should bear a certain stress, it will become obvious that something more than the mere resistance to fracture should be calculated. In cases where the parts are short and bulky, it may do very well to employ the rules for resistance to fracture, and make the parts strong enough to sustain four times the load, but such cases rarely occur ; and where long pieces are loaded to one-fourth of their strength, we may expect most flexure, vibration and instability ; I think every one, who carefully examines the subject, will feel satisfied that the measure of the resistance of a material to flexure, is the only proper measure of its resistance, when it is to be applied where perfect form or unalterable position is desirable ; and the measure of its resistance to permanent alteration when it is used, where flexure is not injurious nor objectionable.

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* Dr. Thos. Young, Natural Philosophy, Vol. II, page 503.

I must not omit to remark, that cast-iron when it fails gives no warning of its approaching fracture, which is its chief defect when employed to sustain weights or moving forces ; therefore care should be taken to give it sufficient strength. And it will be obvious, from the preceding remarks, how much its strength depends upon the skill and experience of the founder.

STRENGTH AND STRESS OF IRON.

125. The following Tables and Explanations refer to the strength and stress of wrought and cast-iron, are based on the experiments of Tredgold, Barlow, Rennie, M. S. Brown, and the rules and deductions resulting from them.

TABLE I.

A Table of the Depths of Square Beams or Bars of Cast-iron of different lengths, to sustain Weights of from one Cwt. to 500 Tons, when supported at the ends and loaded in the middle, the deflexion not to exceed $\frac{1}{40}$ of an inch for each foot in length.*

Lengths in feet.		4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.	36.	38.	40.	
Weight in tons.	Weight in lbs.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Weight.
1/20	112	1·2	1·4	1·7	1·9	2·0	2·2	2·4	2·5	2·6	2·7	2·9	3·0	3·1	3·2	3·3	3·4	3·5	3·6	3·7	1 cwt.
1/10	124	1·4	1·7	2·0	2·2	2·4	2·6	2·8	3·0	3·1	3·3	3·4	3·6	3·7	3·8	3·9	4·1	4·2	4·3	4·4	2 ,,
3/20	336	1·6	1·9	2·2	2·4	2·7	2·9	3·1	3·3	3·4	3·6	3·8	3·9	4·1	4·2	4·3	4 5	4·6	4·7	4·8	3 ,,
1/5	448	1·7	2·0	2·4	2·6	2·9	3·1	3·3	3·5	3·7	3·9	4·0	4·2	4·3	4·5	4·7	4·8	4·9	5·0	5·2	4 ,,
1/4	560	1·8	2·2	2.5	2·8	3·0	3·3	3·5	3·7	3·9	4·1	4·3	4·4	4·6	4·8	4·9	5·1	5·2	5·4	5·5	5 ,,
3/10	672	1·8	2·2	2·6	2·9	3·2	3·4	3·7	3 9	4·1	4·3	4·5	4 6	4·8	5·0	5·1	5·3	5·4	5·6	5 8	6 ,,
7/20	784	1·9	2·3	2·7	3·0	3·3	3·6	3·8	4·1	4·2	4·4	4·6	4·8	5·0	5·2	5·4	5·5	5·7	5·9	6·0	7 ,,
2/5	896	2·0	2·4	2·8	3·1	3·4	3·7	3·9	4·2	4·4	4·6	4·8	5·0	5·2	5·4	5·6	5·7	5·9	6·0	6 2	8 ,,
9/20	1008	2·0	2·5	2·9	3·2	3·5	3·8	4·0	4·3	4·5	4·7	4·9	5·1	5·3	5·5	5·7	5·9	6·0	6·2	6·4	9 ,,
1/2	1120	2·1	2·6	3·0	3·3	3·6	3·9	4 2	4·4	4·7	4·9	5·2	5·3	5·4	5·7	5·9	6·0	6·2	6·4	6·5	10 ,,
11/20	1232	2·1	2·6	3·[illegible]	3 4	3·7	4·0	4·3	4·5	4·8	5·0	5·3	5·4	5·6	5·8	6·0	6·2	6·4	6·5	6·7	11 ,,
3/5	1344	2·2	2·7	3·1	3·5	3·8	4·1	4·4	4·7	4·9	5·1	5·3	5·5	5·7	5·9	6·1	6·3	6·5	6·7	6·8	12 ,,
13/20	1456	2·2	2·7	3·1	3 5	3·8	4·2	4·4	4·7	4·9	5·2	5·4	5·6	5·9	6·0	6·2	6·5	6·6	6·8	7·0	13 ,,
7/10	1568	2·3	2·8	3·2	3·6	3·9	4·2	4·5	4·8	5·0	5 3	5·5	5·7	6·0	6·1	6·4	6·6	6·7	6·9	7·1	14 ,,
3/4	1680	2·3	2·8	3·2	3·6	4·0	4·3	4·6	4·9	5·2	5·4	5·6	5·8	6·1	6·2	6·5	6·7	6·8	7·0	7·2	15 ,,
4/5	1792	2·4	2·9	3·3	3·7	4·0	4·4	4·7	5·0	5 2	5·5	5·7	5·9	6·2	6·4	6·6	6·8	6·9	7·2	7·4	16 ,,
17/20	1904	2·4	2·9	3·4	3·8	4·1	4·4	4·7	5·0	5·3	5·5	5·8	6 0	6·2	6·5	6·7	6·9	7·1	7·3	7·5	17 ,,
9/10	2016	2·4	3·0	3·4	3·8	4·2	4·5	4·8	5·1	5·4	5·6	5·9	6·1	6·4	6·6	6·8	7·0	7·2	7·4	7·6	18 ,,
19/20	2128	2·5	3·0	3·5	3·9	4·2	4·6	4·9	5·2	5·4	5·7	6·0	6·2	6·5	6·7	6·9	7·1	7·3	7·5	7·7	19 ,,
1	2240	2·5	3·0	3·5	3·9	4·3	4·6	4·9	5·2	5·5	5·8	6·0	6·3	6·5	6·8	7·0	7·2	7·4	7·5	7·8	1 ton.
1¼	2800	2·6	3·2	3·7	4·1	4·5	4·9	5·2	5·5	5·8	6·1	6·4	6·6	6·9	7·2	7·4	7·6	7·8	8·0	8·2	1¼ ,,
Deflexion in inches,..		·1	·15	·2	·25	·3	·35	·4	·45	·5	·55	·6	·65	·7	·75	·8	·85	·9	·95	1·0	Def. in.

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* The weight of the load to be supported, must include the weight of the beam. To find the weight of a beam, multiply the area of the section in inches by the length in feet and by 3·2, which will give the weight in lbs.

TABLE I.

Of the Stiffness of Beams.—(Continued.)

Lengths in feet.		4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.	36.	38.	40.	
Weight in tons.	Weight in lbs.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Weight in tons.
1½	3360	2·8	3·4	3·9	4·3	4·7	5·1	5·5	5·8	6·1	6·4	6·7	7·0	7·2	7.5	7·7	8·0	8·2	8·4	8·6	1½
1¾	3920	2·9	3·5	4·0	4·5	4·9	5·3	5·7	6·0	6·3	6·7	6·9	7·2	7·5	7·7	8·0	8·2	8·5	8·7	8·9	1¾
2	4480	2·9	3·5	4·1	4·7	5·1	5·5	5·9	6·2	6·5	6·8	7·2	7·6	7·7	8·0	8·3	8·5	8·7	9·0	9·2	2
2½	5600	3·1	3·8	4·4	4·9	5·5	5·8	6·2	6·6	6·9	7·3	7·6	7·9	8·2	8·5	8·8	9·0	9·3	9·6	9·8	2½
3	6720	3·3	4·0	4·6	5·1	5·7	6·1	6·5	6·9	7·3	7·6	7·9	8·3	8·6	8·9	9·2	9·4	9·7	10·0	10·1	3
3½	7840	3·4	4·1	4·8	5·3	5·8	6·3	6·7	7·1	7·5	7·9	8·2	8·6	8·9	9·2	9·5	9·8	10·1	10·4	10·6	3½
4	8960	3·5	4·3	4·9	5·5	6·0	6·5	7·0	7·4	7·8	8·2	8·5	8·9	9·2	9·5	9·8	10·1	10·4	10·7	11·0	4
4½	10080		4·4	5·1	5·7	6·2	6·7	7·2	7·6	8·0	8·4	8·8	9·1	9·5	9·8	10·1	10·4	10·8	11·0	11·4	4½
5	11200		4·5	5·2	5·8	6·4	6·9	7·4	7·8	8·2	8·6	9·0	9·4	9·7	10·1	10·4	10·7	11·0	11·2	11·6	5
6	13440			5·5	6·1	6·7	7·2	7·7	8·2	8·6	9·0	9·4	9·8	10·2	10·5	10·9	11·2	11·5	11·9	12·1	6
7	15680			5·7	6·3	6·9	7·5	8·0	8·5	8·9	9·4	9·8	10·2	10·6	11·0	11·3	11·7	12·0	12·3	12·7	7
8	17920			5·9	6·6	7·2	7·8	8·3	8·8	9·3	9·7	10·1	10·6	10·9	11·3	11·7	12·0	12·4	12·8	13·1	8
9	20160			6·0	6·8	7·4	8·0	8·5	9·0	9·5	10·0	10·4	10·9	11·3	11·7	12·0	12·4	12·8	13·1	13·5	9
10	22400				6·9	7·6	8·2	8·8	9·3	9·8	10·3	10·7	11·2	11·6	12·0	12·4	12·8	13·1	13·5	13·8	10
11	24640				7·1	7·8	8·4	9·0	9·5	10·0	10·5	11·0	11·5	11·9	12·3	12·7	13·1	13·5	13·8	14·2	11
12	26880				7·2	7·9	8·6	9·2	9·7	10·2	10·8	11·2	11·7	12·1	12·5	13·0	13·4	13·7	14·1	14·5	12
13	29120				7·4	8·1	8·8	9·4	9·9	10·4	11·0	11·5	11·9	12·4	12·8	13·2	13·6	14·0	14·4	14·7	13
14	31360				7·5	8·3	8·9	9·5	10·1	10·6	11·1	11·7	12·1	12·6	13·0	13·4	13·8	14·2	14·6	15·0	14
15	33600				7·7	8·4	9·1	9·7	10·3	10·8	11·4	11·9	12·3	12·8	13·2	13·7	14·1	14·5	14·9	15·3	15
16	35840				7·8	8·5	9·2	9·8	10·4	11·0	11·5	12·0	12·5	13·0	13·5	13·9	14·3	14·7	15·1	15·5	16
17	38080				7·9	8·7	9·4	10·0	10·6	11·2	11.7	12·2	12·7	13·2	13·7	14·1	14·5	14·9	15·4	15·8	17
18	40320				8·0	8·8	9·5	10·1	10·8	11·3	11·9	12·4	12·9	13·4	13·9	14·3	14·7	15·1	15·6	16·0	18
19	42560				8·1	8·9	9·6	10·3	10·9	11·5	12·0	12·6	13·1	13·6	14·1	14·5	15·0	15·4	15·8	16·2	19
Deflexion in inches,…		·1	·15	·2	·25	·3	·35	·4	·45	·5	·55	·6	·65	·7	·75	·8	·85	·9	·95	1·0	Deflex.

If the depth of a cast-iron bar be multiplied by 0·937, the product will be the depth of a square bar of wrought-iron of equal stiffness.

If the depth of a cast-iron beam be multiplied by 1·83, the product will be the depth of a square beam of teak of equal stiffness.

TABLE I.

Of the Stiffness of Beams.—(Continued.)

Lengths in feet.		4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.	36.	38.	40.	
Weight in tons.	Weight in lbs.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Weight in tons.
20	44800					9·0	9·7	10·4	11·0	11·6	12·2	12·7	13·2	13·8	14·2	14·7	15·1	15·6	16·0	16·4	20
22	49280					9·2	10·0	10·7	11·3	11·9	12·5	13·0	13·6	14·1	14·6	15·1	15·5	15·9	16·4	16·8	22
24	53760					9·4	10·2	10·9	11·5	12·2	12·8	13·4	13·9	14·4	14·9	15·4	15·9	16·3	16·8	17·2	24
26	58240					9·6	10·4	11·1	11·8	12·4	13·0	13·6	14·2	14·7	15·2	15·7	16·2	16·7	17·1	17·6	26
28	62720					9·8	10 6	11·4	12 0	12·7	13·3	13·7	14·4	15·0	15·5	16·0	16·5	17·0	17·4	17 9	28
30	67200						10·8	11·5	12·2	12·9	13·5	14·1	14·7	15·2	15·7	16·3	16·8	17·3	17·7	18·2	30
32	71680						11·0	11·7	12·4	13·1	13·7	14·3	14·9	15 5	16·0	16·5	17·0	17·5	18·8	18·5	32
34	76160						11·1	11·9	12·6	13·3	13·9	14·5	15·1	15·7	16·2	16·8	17·3	17·8	18·3	18·8	34
36	80640						11·3	12·0	12·8	13·4	14·0	14·7	15·3	15·9	16·5	17·0	17·5	18·0	18·5	19·0	36
38	85120						11·4	12·2	13·0	13·6	14·3	14·9	15·5	16·1	16·7	17·2	17·8	18·3	18·8	19·3	38
40	89600							12·4	13·1	13 8	14·5	15·1	15·7	16 4	16·9	17·5	18·0	18·5	19·1	19·5	40
42	94080							12·5	13·3	14·0	14·7	15·3	15·9	16·5	17·1	17 7	18·2	18·7	19·3	19·8	42
44	98560							12·7	13·5	14·2	14·9	15·5	16·1	16·8	17·4	17·9	18·5	19·0	19·5	20·0	44
46	103040							12·8	13·6	14·3	15·0	15·7	16·3	17·0	17·6	18·1	18·7	19·2	19·8	20·3	46
48	107520							13·0	13·7	14·5	15·2	15·9	16·5	17·1	17·7	18·3	18·8	19·4	20·0	20·5	48
50	112000								13·9	14·6	15·3	16·0	16·6	17·3	17·9	18·5	19·0	19·6	20·1	20·7	50
52	116480								14·0	14·7	15 5	16·2	16 8	17·5	18·1	18·7	19·2	19·8	20·3	21·0	52
54	120960								14·1	14·9	15·6	16·3	17·0	17·6	18·2	18 8	19·4	19·9	20·5	21·1	54
56	125440								14·3	15·0	15·8	16·5	17·1	17·8	18·4	19·0	19·6	20·1	20·7	21·3	56
58	129920								14·4	15·1	15·9	16·6	17·3	17·9	18·5	19·2	19·7	20·3	20·9	21·4	58
60	134440								14·5	15·3	16·0	16·7	17·4	18·1	18·7	19·3	19·9	20·5	21·1	21·6	60
65	145600								14·8	15·6	16·4	17·1	17·8	18 5	19·1	19·8	20·4	20·9	21·5	22·1	65
70	156800								15·1	15·9	16·7	17·4	18·2	18·8	19·5	20·1	20·8	21·3	22·0	22·5	70
Deflexion in inches, ...		·1	·15	·2	·25	·3	·35	·4	·45	·5	·55	·60	·65	·70	·75	·80	·85	·90	·95	1·0	Deflex.

TABLE I.

Of the Stiffness of Beams.—(Continued.)

Lengths in feet.		4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.	36.	38.	40.	
Weight in tons.	Weight in lbs.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Depth inches.	Weight in tons.
75	168000										17·0	17·7	18·5	19·2	19·8	20·5	21·3	21·7	22·3	22·9	75
80	179200										17·2	18·0	18·7	19·4	20·1	20·7	21·4	22·0	22·6	23·2	80
85	190400										17·5	18·3	19·0	19·7	20·4	21·1	21·7	22·4	23·0	23·6	85
90	201600										17·8	18·6	19·3	20·0	20·7	21·4	22·1	22·7	23·3	23·9	90
95	212800										18·0	18·8	19·5	20·3	21·0	21·7	22·4	23·0	23·6	24·3	95
100	224000											19·0	19·8	20·6	21·3	22·0	22·6	23·3	23·9	24·5	100
110	246400												20·3	21·0	21·8	22·5	23·2	23·8	24·5	25·1	110
120	268800												20·8	21·5	22·3	23·0	23·7	24·4	25·0	25·7	120
130	291200													22·0	22·7	23·5	24·2	24·9	25·5	26·3	130
140	313600														23·2	23·9	24·6	25·4	26·0	26·7	140
150	336000														23·6	24·3	25·0	25·8	26·5	27·2	150
160	358400														23·9	24·7	25·5	26·2	26·9	27·6	160
170	380800															25·1	25·9	26·6	27·4	28·1	170
180	403200															25·5	26·3	27·0	27·8	28·5	180
190	425600															25·9	26·7	27·4	28·2	28·9	190
200	448000															26·2	27·0	27·7	28·5	29·2	200
250	560000															27·6	28·5	29·4	31·0	31·0	250
300	672000															28·9	29·9	30·7	31·5	32·0	300
350	784000															30·0	31·0	32·0	33·0	33·7	350
400	896000															31·1	32·0	32·9	33·9	34·7	400
450	1008000															32·0	33·1	34·0	34·8	35·8	450
500	1120000																33·8	34·8	35·7	36·7	500
Deflexion in inches, . A .		·10	·15	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	·85	·90	·95	1·0	Deflex.

TABLE II.

A Table to show the weight or pressure a Cylindrical Pillar or Column of Cast-iron will sustain with safety, in hundred weights.

Length or height.	2 ft.	4 ft.	6 ft.	8 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.	22 ft.	24 ft.	
Diameter.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Wt. Cwts.	Diameter.
1 In.	18	12	8	5	3	2	2	1	1	1	0	0	1 In.
1½ „	44	36	28	19	16	12	9	7	6	5	4	3	1½ „
2 „	82	72	60	49	40	32	26	22	18	15	13	11	2 „
2½ „	129	119	105	91	77	65	55	47	40	34	29	25	2½ „
3 „	188	178	163	145	128	111	97	84	73	64	56	49	3 „
3½ „	257	247	232	214	191	172	156	135	119	106	94	83	3½ „
4 „	337	326	310	288	266	242	220	197	178	160	144	130	4 „
4½ „	429	418	400	379	354	327	301	275	251	229	208	189	4½ „
5 „	530	522	501	479	452	427	394	365	337	310	285	262	5 „
6 „	616	607	592	573	550	525	479	469	440	413	386	360	6 „
7 „	1040	1032	1013	989	959	924	887	848	808	765	725	686	7 „
8 „	1344	1033	1315	1289	1259	1224	1185	1142	1097	1052	1005	959	8 „
9 „	1727	1716	1697	1672	1640	1603	1561	1515	1467	1416	1364	1311	9 „
10 „	2133	2119	2100	2077	2045	2007	1964	1916	1865	1811	1755	1697	10 „
11 „	2580	2570	2550	2520	2490	2450	2410	2358	2305	2248	2189	2127	11 „
12 „	3074	3050	3040	3020	2970	2980	2900	2830	2780	2730	2670	2600	12 „

EXPLANATION OF THE FIRST TABLE.

126. The first table shows, by inspection, the dimensions of square beams to sustain weights on pressures of from one hundred weight to 500 tons, so as not to be bent or deflected in the middle more than one-fortieth of an inch for each foot in length.

The length is the distance between the supports, as *A B* figure 4, plate 4, and the stress, whether it be from weight or pressure, is supported to act at the middle of the length, as at *C* in the figure. The breadth and depth are supposed to be the same in every part of the length, and equal to one another.

The horizontal row of figures at the top of the table contains the lengths in feet.

The columns at the outsides contain the weights in cwts. and tons, and the second column, on the left-hand side, contains the weights in pounds avoirdupois.

The horizontal row of figures at the bottom shows the deflexion for each length. The other columns show the depths in inches.

EXPLANATION OF THE SECOND TABLE.

127. The second table shows, by inspection, the weight or pressure a cylindrical pillar or column of cast-iron will bear with safety. The pressure is expressed in cwts. and is completed on the supposition that the pillar is under the most unfavorable circumstances for resisting the stress, which happens, when from settlements, imperfect fitting, or other causes, the direction of the stress is in the surface of the pillar *A A′*, as shown in figure 5, plate 4.

The horizontal row of figures along the top of the table contains the lengths or heights of the pillars in feet.

The outside vertical columns of the table contain the diameter of the pillars in inches.

The other vertical columns of the table show the weight in cwts. which a cast-iron pillar, of the heights at the top of the column and of the diameter in the side columns, will support with safety; consequently of the height, the diameter and the weight to be supported, any two being given, the other will be found by inspection.

EXAMPLE AND USE OF THE TABLES.

128. Example 1.—To find the depth of a square bar of cast-iron, twenty feet in length, that would support ten tons, the deflexion not exceeding half an inch.

Find the column in table I., which has the length twenty feet at the top, and in that column, and opposite to ten tons in either of the side columns, will be found the proper depth for the bar, which 9·8 inches.

If the depth 9·8 be multiplied by 1·71, it will give the depth of a square beam of fir that would support the same load with the same deflexion. Thus $1·71 \times 9·8 = 16·76$ inches nearly the depth of the fir beam.

If the depth of a teak beam be required, multiply by 1·83; thus $1·83 \times 9·8 = 17·93$ inches is the depth of a teak beam.

Example 2.—Let it be required to find the depth of a square cast-iron bar to support ten tons without more deflexion than one-tenth of an inch, the length being twenty feet.

By examining the deflexion for twenty feet at the foot of the column in table I., it will be found five times one-tenth of an inch, hence take the depth opposite five times the weight or fifty tons, which is 14·6 inches, the depth required.

When a bar or beam is employed to support a load in the middle, or at any other point of the length, a great saving of the material is made by making the bar thin and deep, provided it be not made so thin as to break sideways.

The depth of a beam is sometimes limited by circumstances, and as no proportion could be given that would suit for every purpose, it is left entirely to the judgment of the person who may use the table. But there is a limit to the depth, which, if it be exceeded, renders the use of cast-iron for bearing purposes very objectionable and dangerous, where the load is likely to acquire some degree of momentum from any cause; for if the depth be increased it renders a beam rigid or nearly inflexible, and then a comparatively small impulsive force will break it. A very rigid beam resembles a hard body: it will bear an immense pressure, but the stroke of a small hammer will fracture it.

In order to mark the point where the depth has arrived at that proportion of the length which makes it become dangerously rigid, I have stopped the column of depths at that point, and should it be required to sustain a greater weight, the breadth must be increased instead of the depth.*

EXAMPLE OF THE USE OF THE SECOND TABLE

129. Example 3.—Let it be required to support the floor of a ware-house by iron pillars, where the greatest load on any pillar will be 70 tons, the height of the pillars being 14 feet.

Seventy tons is equal to 1,400 cwts., and in the column having 14 feet at the head, in the second table, 1,561 cwts. is the nearest weight, and the diameter opposite this weight in the side column is 9 inches, the diameter required.

If it be wished to approach nearer to the proportion, take the mean between the weight above and that below 1,400, that is the mean between 1,561 and 1,185, which is 1,373 or nearly 1,400; hence it appears that a little more than 8½ inches would be a sufficient diameter, but it is seldom necessary to calculate so near.

When pillars are placed at irregular distances, that which carries the greatest load should be calculated for, and if it happen that such a pillar stands 10 feet from the next support on one side, and 6 feet from the next support on the other side, add these distances together, and take the mean for the distance apart; thus—

$$\frac{10+6}{2} = \frac{16}{2} = 8,$$

the mean distance of the supports.

There are two means of increasing the strength of a beam; the one consists in disposing the parts of the cross section in the most advantageous form; the other, in diminishing the beam towards the parts that are least strained, so that the strain may be equal in every part of the length.

If a weight be uniformly distributed over the length of a beam supported at both ends, and the breadth be the same throughout, the line bounding the compressed side should be a semi-ellipse when the lower side is straight,* as shown in figure 6, plate 4.

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* The effect of a load uniformly distributed over the length, is to be considered equal to that of half the load collected at the middle point.

When a rectangular beam is supported at the ends and loaded in any manner between the supports, it may be observed that the side against which the force acts is always compressed, and that the opposite side is always extended, while at the middle of the depth there is a part which is neither extended nor compressed, or in other words, it is not strained at all.

In almost all substances the fracture shows distinctly that a part has been extended and the rest compressed; and in some substances, as wood, lead, tin, wrought-iron, &c., the place of the axis of motion may be observed in the fracture.

STRAINS ON WROUGHT-IRON.

130. A bolt of Welsh iron, 12 feet 6 inches long and 2 inches in diameter, required a strain of 82 tons 15 cwt. to tear it asunder. When subject to a strain of 68 tons, it stretched 3 inches, and was reduced to 1$\frac{15}{16}$ inch in diameter. When the strain was increased to 74 tons 15 cwt., it had stretched 6 inches, and was reduced $\frac{1}{8}$ of an inch gradually in the diameter. With 82 tons, it stretched 14 inches. With 82 tons 15 cwt. the bolt broke about 5 feet from the end, the levers being exactly balanced. It had stretched during the whole process 18$\frac{1}{2}$ inches, and measured at the place of rupture 1$\frac{5}{8}$ inch in diameter.

A bar of cast-iron, Welsh pig 1$\frac{1}{4}$ inch square, 3 feet 6 inches long, required a strain of 11 tons 7 cwt. to tear it asunder; broke exactly transverse, without being reduced in any part; quite cold when broken; particles fine, of dark blueish-grey color.

Mr. Barlow gives the mean of Captain Brown's experiments with wrought-iron, ... 25 tons.
The mean of Mr. Telford's experiments, ... 29$\frac{1}{4}$ tons.
And the mean of the two is .... 27 tons nearly,
which may be safely assumed as the medium strength of an iron bar 1 inch square† to resist tension.

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* Gregory's Mechanics, i. Art. 182, or Emerson's Mechanics, prop. LXXVII., Cor. 3.

† Barlow's Essay, 2nd edition, page 258.

In practice one-third or 9 tons is the extreme strain to which a rod or bar of one sectional inch should be permanently exposed.

131. It is found in practice, that a number of small bars thus laid together, will bear a greater proportion of load than a single bar equal to the sum of all their areas. This anomaly is believed to proceed from the greater perfection with which small bars may be wrought and prepared than large ones, as all metals are improved in their strength by hammering or wire-drawing, so the effect of hammering 16 small bars separately will add more to their strength than hammering on a large bar equal to the sum of their areas. Metals can only be improved in their strength by hammering or wire-drawing, in consequence of these operations forcing their constituent particles into a closer state of aggregation; and this can easily be done in small bars, because from their want of re-action, they yield to every blow of the hammer, and its effect is transmitted through their whole substance, while the re-action of a large and heavy bar opposes this effect, and the condensation is more confined to the surface. A number of small bars acting simultaneously, are therefore found to produce more strength than one large bar equal in size to their sum. It likewise explains why a faggotted bar of iron should be stronger than one that has not undergone the operation.

A bar of Swedish iron 1 inch square and 3 feet between the bearings, bore a load of 560 lbs. in the middle, and was deflected by it ¼ inch.*

With 716 lbs. the deflection was .... ·375 inch.
With 884 .... ·5 inch.

Being then relieved of its load, the bar resumed a rectilinear form.

With 1,120 lbs. the deflexion was 1 inch, and the elasticity of the bar was destroyed.

As a mean, Mr. Barlow states 1,000 lbs. for the load that will destroy the elasticity of a bar of wrought-iron, supported at both ends, 1 inch square and 3 feet long between the supports.

Mr. Barlow does not state at what load flexure was first sensible; but if a bar was deflected ¼th of an inch by 560 lbs., it may be assumed that it would not be safe to load it permanently with more than 280 lbs. Taking therefore

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* Barlow's Essay, 3rd edition, page 278.

280 lbs. as the strain that a bar of iron 3 feet long and 1 inch square will bear without injury, a bar 1 foot long and 1 inch square will bear 840 lbs. in the middle, or say 800 lbs. as a more convenient number for calculation, and on the safe side, since it will give a somewhat greater strength. On these data the following rule proceeds:

132. To find the proper diameter for a round wrought-iron bolt at rest, supported at both ends and loaded in the middle.

RULE.—Multiply the strain in pounds by the length of the bolts in feet between their supports, and divide the product by 800. The cube root of the quotient is the proper diameter for the bolt.* If the bolt is to be loaded uniformly over the length instead of in the middle, then divide by 1,600 instead of 800.

EXAMPLE.—In the Menai Bridge, each of the bolts, that retain the 16 chains, must bear 125 tons, since the whole strain on the chains may amount to about 2,000 tons. The length of each bolt between its bearings against the rock, is 18 inches, and the chains are disposed along that length; therefore the divisor will be 1,600.

Then:

(Strain in lbs. =)2,80,000 lbs. × 1·5 feet = 262·5. The cube root of which is $6\frac{4}{10}$ inches for the diameter of the bolt; the actual diameter is 6 inches.

The foregoing rule is adapted to proportion the strength of a bolt to bear $3\frac{3}{4}$ times the strain it is exposed to, before losing its elasticity, and will give sufficient strength for the retaining bolts of Suspension Bridges which are at rest.

OF THE STRENGTH AND DEFLEXION OF CAST-IRON WHEN IT RESISTS PRESSURE OR WEIGHT.

133. The doctrine of the strength of materials rests upon three first principles, and these are abundantly proved by experience.

The first is, that the strength of a bar or rod, to resist a given strain when drawn in the direction of its length, is directly proportional to the area of its cross section; while its elastic power remains perfect and the direction of the force coincides with the axis.

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* Because the strength of bars of iron is inversely as the length, and directly as the breadths and squares of the depths, and therefore, when the bars are round, the strengths are as the cubes of the diameter.

The second is, that the extension of a bar or rod by a force acting in the direction of its length, is directly proportional to the straining force, when the area of the section is the same; while the strain does not exceed the elastic power.[*]

The third is, that while the force is within the elastic power of the material, bodies resist extension and compression with equal forces.

It is further supposed that every part of the same piece of the material is of the same quality, and that there are no defects in it. If there be any material defect in a piece of cast-iron, it may often be discovered, either by inspection, or by the sound the piece emits when struck; except it be air-bubbles, which cannot be known by these means.

A free weight or mass of matter is always to be considered to act in the direction of a vertical line passing through its centre of gravity; and its whole effect as if collected at the point where this vertical line intersects the beam or the pillar, which is to support it. But if the weight or mass of matter be partially sustained, independently of the beam or pillar, in any manner, then the direction and intensity of the force must be found that would sustain the mass in equilibrium, and this will be the direction and intensity of the pressure on the beam or pillar.

The strain upon a beam supported upon a fulcrum, as in figure 7, plate 4, is obviously the same as when one of the ends is fixed in a wall, or other like manner, for fixing the end merely supplies the place of the weight otherwise required to balance the straining force. But though the strain upon the beam be the same, the deflexion of the point where the strain is applied will vary according to the mode of fixing the end; because the deflexion of the strained point will be that produced by the curvature of both the parts *A B* and *B A′*.[†]

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[*] This limit should be carefully attended to, for as soon as the strain exceeds the elastic power, the ductility of the material becomes sensible. The degrees of ductility are extremely variable in different bodies, and even in different states of the same body. A fluid possesses this property in the greatest degree, for every change in the relative position of its parts is permanent.

[†] This is a practical deduction from an abstruse algebraical calculation which is omitted, but may be found in "Tredgold on Cast-iron," p. 149.

When the same beam is supported at the ends, as in figure 8, instead of being loaded at the ends, and supported in the middle, as in figure 7, and the inclination and sum of the load be the same in both positions, the strains will be the same.

PRACTICAL RULES AND EXAMPLES.

134. RULE 1.—To find the breadth of an uniform cast-iron beam, to bear a given weight in the middle.

Multiply the length of bearing in feet by the weight to be supported in pounds and divide the product by 850 times the square of the depth in inches; the quotient will be the breadth in inches required.*

RULE 2.—To find the depth of an uniform cast-iron beam, to bear a given weight in the middle.

Multiply the length of bearing in feet by the weight to be supported in pounds, and divide this product by 850 times the breadth in inches; and the square root of the quotient will be the depth in inches.

When no particular breadth or depth is determined by the nature of the situation for which the beam is intended, it will be found sometimes convenient to assign some proportion; as for example, let the breadth be the nth part of the depth, n representing any number at will. Then the rule becomes,

RULE 3.—Multiply n times the length in feet by the weight in pounds; divide this product by 850, and the cube root of the quotient will be the depth required: and the breadth will be the nth part of the depth.

It may be remarked here, that the rules are the same for inclined as for horizontal beams, when the horizontal distance FF' figure 8, is taken for the length of bearing.

135. EXAMPLE 1.—In a situation where the flexure of a beam is not a material defect, I wish to support a load which cannot exceed 33,600 lbs. (or 15 tons) in the middle of a cast-iron beam, the distance of the supports being 20 feet, and making the breadth a fourth part of the depth.

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* If the bar is to be of wrought-iron, divide by 952 instead of 850.

* If the beam be of teak, divide by 212 instead of 850.

In this case

$$n = 4 \text{ and } \frac{4 \times 20 \times 33600}{850} = 3162 \cdot 35.$$

The cube root of 3162·35 is nearly 14·68 inches, the depth required; the breadth is

$$\frac{14 \cdot 68}{4} = 3 \cdot 87 \text{ inches.}$$

In practice therefore I would use whole numbers, and make the beam 15 inches deep and 4 inches in breadth.

When the load is uniformly distributed over the length of a beam, which is supported at both ends.

In this case the same rules apply as in Art. (134,) by making the divisor twice 850, or 1700.

Example.—In a situation where I cannot make use of an arch for want of abutments, it is necessary to leave an opening 15 feet wide, in an 18 inch brick wall; required the depth of two cast-iron beams to support the wall over the opening, each beam to be 2 inches thick, and the height of the wall intended to rest upon the beam being 30 feet?

The wall contains—

$$30 \times 15 \times 1\tfrac{1}{2} = 675 \text{ cubic feet.}$$

and as a cubic feet of brick-work weighs about 100 lbs., the weight of the wall will be about 67,500 lbs., and half this weight, or 33,750 lbs., will be the load upon one of the beams. Since the breadth is supposed to be given, the depth will be found by Rule 2, Art. 134, if 1700 be used as the constant divisor, thus—

$$\frac{15 \times 33750}{1700 \times 2} = 149 \text{ nearly.}$$

The square root of 149 is 12¼ nearly, therefore each beam should be 12¼ inches deep and 2 inches in thickness. This operation gives the actual strength necessary to support the wall; but it is usual to take double the calculated weight in practice, to allow for accidents.

In this manner the strength proper for bressummers, lintels, and the like may be determined.

136. A fire-proof floor is usually formed by placing parallel beams of cast-iron across the area in the shortest direction, and arching between the

beams as shown by figure 10, plate 4, with brick or other suitable material. Or they may be done by flat plates of iron resting on the ledges, with one or two courses of bricks paved upon the iron plates; and when the distance of the joists is considerable, the iron plates may be strengthened by ribs on the upper side as the floor plates of iron bridges are made.

When arches are employed, floors of this kind are least expensive when the arches are of considerable span, but then it is necessary to provide against the lateral thrust of the arches by tie bars. Also since the arches ought to be flat, we can only extend them to a limited span, otherwise they would be too weak to answer the purpose. For instance when an arch is to rise only $\frac{1}{10}$th of the span and to be half a brick or 6 inches thick,* the greatest span that can be given to the arch with safety in a floor for ordinary purposes is 5 feet. If the arch rise only $\frac{1}{12}$th of the span, the span must be limited to 4 feet; and if it rise only $\frac{1}{17}$th of the span, it must be limited to 3 feet.

Again for arches of one brick, or 12 inches, to bear the same load, and the rise $\frac{1}{10}$th of the span, the greatest that can be given with safety is 8 feet,† when the rise is $\frac{1}{12}$th of the span, 7 feet; and when the rise is only $\frac{1}{17}$th of the span, the greatest span should not exceed 5 feet.

These limits were calculated from the ordinary strength of brick, and on the supposition that the load upon the floor will never be greater than 170 lbs. upon a superficial foot, in addition to the weight of the floor itself. If the load be greater, the span must be less, or the rise greater.

For half brick arches the breadth of the beam *c d*, figure 9, should be about 2 inches; and for 9 inch arches from $2\frac{1}{2}$ to 3 inches.

EXAMPLE.—It is proposed to form a fire-proof room, but from its situation it cannot be vaulted in the ordinary way on account of the strong abutments required for common vaulting, and also common vaulting is objectionable, because so much space is lost in a low room. The shortest direction across the room is 12 feet, and if iron beams of 3 inches breadth be laid across at 5 feet apart, and arched between with 9 inch brick arches, it is required to find the depth for the beams? See figure 10, plate 4.

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* Rad. of Curv. 6·75 feet.

† Rad. of Curv. 15·6 feet.

The quantity of brick-work resting upon 1 foot in length of joist will be—

$$5\times{\cdot}75 = 3{\cdot}75 \text{ cubic feet.}$$

and the weight of a cubic foot being nearly 100 lbs., the weight of the brick-work will be 375 lbs.

But since the space above is to be used; and the greatest probable extraneous weight that will be in the room will arise from its being filled with people, we may take that weight at 120 lbs. per superficial foot, and we have

$$5\times120 = 600 \text{ lbs.}$$

for the weight on 1 foot in length. And supposing the paving and iron to be 350 lbs. for each foot in length; the whole load on a foot in length, will be—

$$375+600+350 = 1235 \text{ lbs. or}$$

$$12\times1325 = 15{,}900 \text{ lbs.}$$

the whole weight upon one joist. And as half this weight multiplied by the length, and divided by the breadth and constant number,* is equal to the square of the depth, we have

$$\frac{7950\times12}{675\times3} = 47{\cdot}11$$

of which the square root is nearly 7 inches the depth required, and

$$7\times{\cdot}7 = 4{\cdot}9 \text{ inches}$$

the depth of the middle part, and

$$3\times{\cdot}4 = 1{\cdot}2$$

the breadth of the middle part.

By fixing the breadth, you avoid the risk of calculating for a thinner beam than is sufficient to support firmly the abutting course of bricks.

By means of this example we may easily form a small table of the depth of beams for fire-proof floors, which will be often useful in so doing. I shall not regard the difference between the weight of a 12 inch and a 6 inch floor, because the lighter floor will be more liable to accidents from percussion, and therefore should have excess of strength.

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* Determined from a Rule, with Algebraical formula attached, for finding the depth of a beam to resist a given force when the strain does not exceed the elastic force of cast-iron. "Tredgold on Cast-iron," p. 181.

137. Table of cast-iron joists for fire-proof floors when the extraneous load is not greater than 120 lbs. on a superficial foot.

Length of Joists in Feet.	Half brick arches, breadth of beams 2 inches.			12 inch arches, breadth of beams 3 inches.		
	3 Feet Span.	4 Feet Span.	5 Feet Span.	6 Feet Span.	7 Feet Span.	8 Feet Span.
Feet.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.	Depth in inches.
8	4½	5¼	5¾	5¼	5¾	6
10	5½	6½	7	6½	7¼	7½
12	6¾	7¾	8½	7¾	8½	9
14	7¾	9	10	9¼	10	10½
16	9	10¼	11¼	10½	11½	12
18	10	11¾	12¾	11¾	13	13½
20	11¼	13	14	13	14¼	15
22	12¼	14¼	15½	14¼	15¾	16½
24	13¼	15½	17	15½	17	18

For half brick arches the breadth *a b*, (figure 9, plate 4,) is to be 2 inches, and the thickness of the middle part $\frac{8}{10}$ths of an inch, the depth of being $\frac{7}{10}$ths of the whole depth, and the whole depth is given in inches in the table for each length and span.

For 12 inch arches the breadth *a b*, (figure 9,) is to be 3 inches, and the breadth of the middle part 1 inch and $\frac{2}{10}$ths. The depth $\frac{7}{10}$ths of the whole depth, as in the 6 inch arches.

If the floor be for a room of greater span than about 16 feet, let the beams be put 8 feet apart; and put the beams for 8 feet bearing across at right angles to the other, in the manner of binding joists, and arch between the shorter beams. By casting the shorter beams with flanches at the ends, they can be bolted to the other, and a complete firm floor be made. This method has also the advantage of rendering it extremely easy to fix either a wooden floor or a ceiling.

The construction of these floors renders a place secure from fire without loss of space, and with very little extra expense; it may be of infinite use in the preservation of deeds, libraries, and indeed of every other species of property. In a public museum, devoted to the collection and preservation of the scattered fragments of literature and art, it is extremely desirable that they should be guarded against fire; otherwise they may be involved in one common ruin, more dreadful to contemplate than their widest dispersion.

CHAPTER VI.

TIMBER.

NATURE AND PROPERTIES.

138. *THE structure of wood, and the nature of the vessels through which the fluids move in the living plant, are not thoroughly understood: indeed the study of vegetable anatomy is attended with considerable difficulties; but some important facts have been ascertained which contribute materially towards a more perfect knowledge of the nature and properties of wood.

Wood appears to be composed of various vessels, which in the living tree convey the fluids necessary to its growth; between those vessels there are cells interposed. The vessels in the growing tree are intended to convey a watery fluid called the sap, from the roots to the leaves, when it arrives at the leaves it undergoes certain changes, and returns through the bark; and the bark being expanded by this accession of moisture, rises from the wood, and leaves a cavity that becomes filled with the proper sap, which gradually hardens and forms a new layer of wood.

The sap which rises through the wood from the roots, is very different in its nature from that which descends through the bark to form a new layer of wood. That which ascends is nearly as liquid as water, and is called the common sap. It has in general a sweetish taste, and contains sugar and mucilage;

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* Tredgold.

it always contains an acid, sometimes in a free state, sometimes combined with lime or potash. When this sap is left to itself, it soon ferments and becomes sour; and when the proportion of sugar is considerable, it will undergo the vinous fermentation. The descending sap called the proper sap, differs so considerably in different trees, and is so difficult to procure in a separate state, that its properties have not been much examined.

That part of the wood next the bark is called sap-wood, because it is through it chiefly that the sap ascends, and as it is shown to contain some vegetable matter to be expanded in forming leaves and buds, it is reasonable to suppose that the sap-wood must be more prone to decay than the internal part of the tree, called the heart-wood.

As trees increase in size, the oldest part of the sap-wood gradually loses all vegetable life, and the more fluid parts of it are either absorbed by the new forming sap-wood, or evaporated; its vessels and cells become closed by the pressure of the new forming wood, and it ceases to perform any other part in the growth of a tree than to support it. When these changes have taken place, it is found to be more compact, and generally of a darker color; and also contains only a small proportion of vegetable matter. It is then heart-wood, or wood in its most perfect state. The sap-wood is softer and generally lighter colored than the heart-wood, and contains a considerable portion of vegetable matter, which partakes of the nature of the sap, and which ascends through it. It is found to decay rapidly, and is also very subject to worms. The reason is obvious, for it contains the food which they live upon, the most of which is absorbed or evaporated from the heart-wood.

FELLING.

139. To the timber-grower the object aimed at should be that of obtaining the largest quantity of hard and durable wood, as free from sap as possible: no tree should be severed from its stool until it has arrived at a state of maturity, and previous to its being thrown down, the natural juices which pervade it should be discharged and allowed to run out, that the wood may be freed from what would bring about premature decay, and prevent its becoming dry and hard.

"Barking" the tree whilst in a growing state, and cutting through the sap or sap-wood called "Ringing," so as to allow the juices to be discharged, are practices of high antiquity, and might be advantageously practised in India. Both the density and the strength of timber are much improved by causing the tree to die standing: and most persons have agreed that barking the timber, previous to felling, greatly improves its quality. When a tree has an incision made through the sap-wood at its trunk, it soon dies and no further change takes place; and the barking of trees, when in full growth and vigour, and letting them stand a twelvemonth after the operation, is admitted not only to improve the quality but to increase the quantity; at the same time that it seasons the wood: time however, is the best seasoner, and no artificial method can equal the natural process, which is that of getting rid of all juices in so regular a manner, that dissipating them does not too rapidly shrink and crack the timber. Trees may be suffered to stand too long before they are cut down; but this is not a usual fault, for often they are marked for felling, the heart-wood not having either acquired its hardness or its full quantity.

All timber in India is felled during the cold weather, though in the case of Saul, which is an evergreen, its bark will peel as freely from a tree felled in June, as from one cut in December.

The Natives have a bad practice of felling with the axe, whereas the saw should be used instead.

SEASONING.

140. *Nothing more effectually contributes to this purpose than suffering timber to lie for a time in fresh water; thus the natural juices of the tree are removed by the water penetrating throughout its pores; this not containing any quality to produce fermentation, and being afterwards easily evaporated, tends to improve it for building purposes. Salt-water, on the contrary, would require a considerable time to evaporate from the wood, in consequence of its deliquescence, and would render it unfit for use: when taken out of the water, it should be suffered to become thoroughly dry before it is carried to the pit to be sawn; the usual method adopted is to block it up from the ground, and suffer

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* Cresy. Encyclopedia.

a free circulation of air around it. When the tree is cut into scantlings, a further seasoning should be permitted by a free exposure to air, guarding against too violent an effect of wind or the sun's rays, and if it be cut into boards, they should be piled one on the other, with fillets or small pieces of wood between them, or laid in a triangular form, with their ends alternating so as to permit the air to pass freely about them.

Gradual drying should always be resorted to, as it invariably produces the most durable timber, the object of seasoning being chiefly to drive off the water, and not to disturb any portion of the carbon, which would certainly be the consequence of elevating the temperature of the wood, or exposing it to great heat. Timber dried too quickly loses its toughness as well as its pliability; the outer pores become rapidly contracted, and do not permit the moisture from within to pass off freely.

Experiment has proved that saul when seasoned properly, has lost rather more than two-fifths of its weight, showing the necessity of allowing a sufficient time for the juices to be thoroughly driven off, which time must vary in proportion to the scantling of the timber, if cut into thin planks, the operation of seasoning would be perfected in quicker time than that which would be necessary for the entire tree. All timber should be permitted to arrive at this dry state before it is cut into smaller scantlings or planks; great shrinking being the consequence of their suddenly drying by exposure to the air, which, by disturbing the fibres of the wood, affect its durability.

Where posts or piles are to be driven or plunged into the earth, it has been from the earliest time customary to char the surface to be placed under ground: but to apply this practice to green timber is injurious, as it confines within, rather than expels these juices, which by fermenting cause its decay; it may be serviceable in destroying any fungi or worms that may attach themselves, or prevent their preying upon the fibres of the wood.

141. Timber, when properly seasoned, is strong, tough and elastic; but it does not long retain those properties in any state or situation. Timber is generally employed in situations where it is continually dry, where it is constantly wet, where it is alternately wet and dry, or where it is exposed to heat and continued moisture. Timber that is constantly dry, or affected only by the small quantity of moisture it absorbs from the air in damp weather, has

been known to last for seven or eight hundred years; but even in this state, time produces a sensible alteration in its properties; for it is found to lose its elastic and coherent powers gradually, and to become brittle. Hence it is unfit to sustain the action of variable loads, though in a state of rest it may endure an immense length of time.

The well-seasoned timber employed by the carpenters of the middle ages, in the old English halls particularly, as well as in Churches and Chapter-houses, needed neither paint nor dressing of any kind to preserve them; and in many instances they are found sound after four or five centuries. The weather-boarding of our English barns, which, in many instances, is of undressed elm timber, owes its duration to a hard external surface, which it acquires by time, and which resists almost the edge of a sharp tool, or the point of a nail, apparently a coating of silica, quite impervious to water, or even the action of moisture; this silica may be derived from the decomposition of the wheat-straw with which the barns are usually thatched.

142. When the Engineer or the carpenter selects timber for the purposes of construction, due regard must be paid to its firmness, density and strength, without which qualities no solid or durable works can be executed. The great weight with which timber is sometimes loaded, placed vertically or horizontally, shows at once the caution which should be used in its selection, and when it is exposed to the action of the air, the necessity of having it so seasoned and protected, that it should not be subject to decay. When employed in the formation of centres to the arch of a bridge, durability for a time only is required, but in permanent roofs and floors it should be capable of resisting all efforts which may destroy its utility or strength; its warping and shrinking in edifices entirely formed of it lead sometimes to the greatest inconveniences, as the strength of a truss may be entirely destroyed by this cause.

143. Quick lime, when assisted by moisture, has a powerful effect in hastening the decomposition of wood, in consequence of its abstracting carbon. Mild lime (carbonate of lime) has not this effect; but mortar requires a considerable time to bring it to the state of mild lime; therefore, bedding timber in mortar, or building it in walls where it will long remain in a damp state in contact with mortar, is very injurious, and often the cause of rapid decay. Wood, in a perfectly dry state does not appear to be injured by dry lime; of this we have

examples in plastering laths, which are generally found sound and good in places where they have been dry. Lime also protects wood from worms.

Warmth and moisture are the most active causes of decay, and provided the necessary degree of moisture be present, the higher the heat the more rapid is its progress. In warm cellars, or in any close confined situations where the air is filled with vapour without a current to change it, the rot proceeds with astonishing rapidity, and the timber-work is destroyed in a very short time. The bread-rooms of ships, behind skirtings and under the wooden floors, or the basement stories of houses; and in general, in every place where wood is exposed to warmth and damp air, the dry rot will soon make its appearance.

144. Building timber into new walls is often a cause of decay, as the lime and damp brick-work are active agents in producing putrefaction, particularly where inferior brick-dust is used instead of sand for mortar.

The bad effects resulting from damp walls is still farther increased by hasty finishing. To enclose with plastering and joiner's work the walls and timbers while they are in a damp state, is the most certain means of causing the building to fall into a premature state of decay.

145. There is another cause that affects all wood most materially, which is the application of paint, tar or pitch, before the wood has been thoroughly dried. The nature of these bodies prevents all evaporation, and confines the internal moisture, which is the cause of sudden decay.*

PRESERVATION FROM DECAY AND INSECTS.

146. Various have been the processes resorted to during the last few years for preventing decay in timber and with various degrees of success, the following are amongst the most prominent, but whatever the artificial mode of proceeding may be by which the Engineer or Architect seeks to preserve his timber from rot or insect, he should first take care that it is seasoned naturally, which is, that the natural juices of the tree no longer exist in the pores; thus attempts at *preservation*, should ever succeed *seasoning*.

147. Mr. Kyan in 1832, introduced the process of preserving timber from decay by a solution of corrosive sublimate of mercury, and the wood of ships'

Tredgold, p. 201.

roofs, floors, railway-sleepers and various other works, have been subjected to kyanization. At first the timber was subjected to saturation only, a considerable time having been allowed to allow of the solution thoroughly entering the pores, but latterly it was the custom to pile it inside iron tanks, the air being exhausted by a pump to a vacuum of 25½ inches of mercury, the solution was then admitted, and forced into the wood by a force pump at a pressure of 100 lbs. The solution used for the saturation contained 224 lbs. of the sublimate to 1,062 gallons of water or about 1 lb. to 5 gallons, the strength of which was said not to diminish by use.

148. There were objections to the kyanizing process, which of late years have thrown it out of use save partial application to timber having continuous bearing and not subjected to strains, such as railway-sleepers. It was found that the mercury considerably impaired the elasticity of the fibres of the wood, whilst it increased its hardness, it was besides often prejudicial to the health of those who dabbled much in the solution, and it was also found to be soluble in salt water which prevented its further use in the Navy. This process was succeeded in 1841 by Sir Wm. Burnett's, which was chloride of zinc, and is decidedly superior in every way both for the preservation of timber, canvas, rope, and all articles likely to be attacked by ants or other insects. The mode of application is the same as that for Kyan's solution, but the simple saturation does not take so long, 30 days sufficing for the zinc to penetrate a scantling 10″×8″. The liquid from the Galvanic batteries used at the Mint in Calcutta, was employed with success in Fort William in saturating timber, canvas, bamboos, &c., laid in iron tanks; it is besides an economical preparation.

Timber of various scantling and bamboos that were immersed in chloride of zinc in June and July 1846, were examined in 1852, and found quite sound from rot or white-ant, though piled up in an open shed where the white-ant abounds and exposed to alternate heat and moisture. One piece had been buried in a fungus pit for five years, and was quite sound. So also were bamboos, which under ordinary circumstances, decay, or are eaten by the worm in two years.

149. The use of the solution of the sulphate of copper as a preservative of wood from decay, was patented by Mr. Margary, in the year 1837, it is mentioned however by Brande in his Manual of Chemistry, 4th edition, 1836,

(possibly in earlier editions); also as a preventive against dry rot, and is said to be one of the most efficacious and cheapest re-agents for the prevention of decay in wood, and to be moreover a destructive poison to insects.

For impregnating wood with the solution of the sulphate of copper, a large wooden trough should be prepared about 35 feet long × 3 feet square, and should be covered when in use to prevent evaporation: great care will be necessary that no iron shall appear inside the trough as this would cause a deposition of metallic copper, but to secure a water-tight condition of the trough, it may be strapped with iron outside and well caulked: for steeping small scantlings and bamboos, the troughs may be made shorter.

The process of preserving with sulphate of copper consists in steeping the substances to be preserved in a solution of the following strength,—sulphate of copper 1 lb. to 7 gallons of water, leaving them in it till thoroughly saturated. For this purpose allow two days for every inch of thickness of the timber.

From a variety of experiments, it appears that 50 cubic feet absorb 24 gallons of the solution, from these data the sulphate being from rupees 10 to 13 per maund, the cost of the preparation of timber can be calculated.

The sulphate of copper appears to be a more convenient re-active than any, except the chloride of zinc. It forms an insoluble compound in the wood and is neither deliquescent nor expensive. As this salt is not volatile the health of the workmen is not endangered. It is not acid like the sulphate of the protoxide of iron and therefore does not attack the fibres of the wood.

150. The preservation of timber by creosote or distillation of coal tar, has lately been successfully carried out; it was the plan originally adopted by Mr. Bethel. When injected into wood, the creosote coagulates the albumen and prevents putrefactive decomposition, the bituminous oil enters the whole of the capillary tubes, encasing the woody fibre as with a shield and closing all the pores against both air and water. The oil is insoluble in water and unaffected by any atmospheric change.

Inferior timber even, or timber cut too young, is by the injection of creosote rendered durable and useful. It is a great preservative also against the teredo worm.

One process of injection is precisely the same as that for the corrosive sublimate, *viz.*, by exhaustion of air from the tanks till a vacuum equal to 12 to

15 lbs. per square inch is created, then follows the injection by a force pump. The timber requires to be well and perfectly dry, as the creosote will not enter the pores if moisture exists. In consequence of which Mr. Bethel constructed a drying house for the purpose of more thoroughly getting rid of all moisture. (Figures 1, 2, plate 5,) show the longitudinal and cross sections. *A A* drying house with hollow walls filled with ashes, *B* fire place, *C C* flue, the whole length of building covered with iron plates perforated for half the length furthest from the fire, to allow the products of combustion to pass through the timber on its way to the chimney; *D* carriages for holding the timber *E*, that is to be creosoted, running on a rail to facilitate the charging and discharging; *F* iron doors closing the end of the house.

The timber is thus not only dried rapidly, but impregnated to a certain extent with the volatile oily matter given out from the fuel used to heat the house. When the timber is taken out, it is at once immersed in hot creosote in an open tank, thus avoiding the use of engine, air, or force-pump. The above drying process might be advantageously adopted before applying either chloride of zinc or sulphate of copper; and is by no means expensive compared with the benefit derived.

The pieces of timber should be weighed before immersion, and after, as each cubic foot is required to be increased 10 lbs. by the process of creosoting.

When timber is exposed to the alternate action of dryness and moisture, the best means of securing it from moisture is the protection of the surface by a coat of some substance that moisture will not penetrate.

151. The Dutch for the preservation of their gates, draw-bridges, sluices, and other large works of timber, which are exposed to the sun and perpetual injuries of the weather, coat them with a mixture of pitch and tar, upon which they strew small pieces of cockle and other shells, beaten almost to powder, and mingled with sea-sand, or the scales of iron beaten small and sifted, which protects them in a most excellent manner.

Upon common priming, sanding is an excellent practice, where it is exposed to the weather, being much more durable than painting, as it forms a coat of silica, impervious to moisture.

152. There is another method of protecting timber, which appears to be so well calculated for the purpose, that in cases where it can be applied a better

cannot be employed. After your work is put together, lay it on the ground with stone or bricks under it to about a foot high, and burn wood (which is the best firing for that purpose) under it till you thoroughly heat, and even scorch it all over; then whilst the wood is hot, rub it over plentifully with linseed oil and tar, in equal parts, well boiled together, and let it be kept boiling whilst you are using it; and this will immediately strike and sink (if the wood be tolerably seasoned) one inch or more into the wood, close all the pores, and make it become exceedingly hard and durable, either under or over water.*

No composition should however be applied till the timber has been well seasoned; for to inclose the natural juices of the wood is to render its rapid decay certain.

153. The bottoms of ships and timbers exposed to the action of the sea, are often destroyed by the pipe-worm or "teredo navalis" of naturalists. This creature is very small when first produced from the egg, but soon acquires a considerable size, being often three or four inches in length, and sometimes increases to a foot or more in length. Its head is provided with a hard calcareous substance, which performs the office of an augur, and enables it to penetrate the hardest woods. When a piece of wood constantly under water, is occupied by these worms, there is no sign of damage to be seen on the surface, nor are the worms visible till the outer part of the wood is broken or cut away; yet they lie so near the surface as to have an easy communication with the water by a multitude of minute perforations. They were originally brought from India to Europe. A mixture of lime, sulphur and colocynth, with pitch, is found to be a protection to boards and the like, and rubbing the wood with poisonous ointments is a means of destroying these worms.†

154. The "Lepisma" is also a destructive little animal which begins to prey on wood in India, as soon as it is immersed in sea water. The unprotected bottom of a boat has been known to be eaten through by it in three or four weeks: sheathing with copper or covering with felt, are the most certain means of protection against all these marine animals.

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* Temple on building in water, p. 85.

† Rees's Cyclopœdia, Art. "Teredo."

155. Coal-tar is also a good protection against their depredations. The pores of the wood should be saturated as far as possible with it, and perhaps corrosive sublimate might be used with advantage, by saturating the wood with a solution of it, and letting it dry before the tar be laid on.

156. The termite or white-ant is represented by Linnœus, is the greatest calamity of both Indies, because of the havoc they make in all buildings of wood, in utensils, and in furniture; nothing but metal or stone can escape their destructive jaws. They frequently construct nests within the roofs and other parts of houses, which they destroy if not speedily extirpated. The larger species enter under the foundations of houses, making their way through the floors, and up the posts of buildings, destroying all before them. And so little is seen of their operations, that a well-painted building is sometimes found to be a mere shell.

Corrosive sublimate is highly poisonous to these ants; therefore, to impregnate the timber with a solution of it, would prevent their ravages.* Arsenic is also very destructive to them; and they do not destroy wood impregnated with oil, particularly essential oils. The chloride of zinc is, as has been shown (para. 148), the most certain method of preventing their attack.

NATURE AND PROPERTIES OF TIMBER.

157. †The only properties of wood which seem to require explanation are the cohesive force, the modulus of elasticity, permanent alteration, the stiffness, the hardness, and the toughness.

The cohesive force of a bar or beam is equal to the power or weight that would pull it asunder in the direction of its length. The weight that would pull asunder a bar of an inch square of different kinds of wood, has been ascertained by careful experiments.

158. The modulus of elasticity is the measure of the elastic force of any substance. As it is the measure of the elastic force, its use must be evident

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* Corrosive sublimate is not to be applied to timber exposed to any kind of tensile strain for the reason given in (para. 148.)

† Tredgold.

when it is considered that it is only the elastic force of timber that is employed in resisting the usual strains in carpentry.[*]

By means of the modulus of elasticity the comparative stiffness of bodies can be ascertained. For instance, its weight for cast-iron is 18,240,000 pounds, and its weight for oak is 1,714,500 pounds. Hence it appears that the modulus for cast-iron is 10·6 times that of oak, and therefore a piece of cast-iron is 10·6 times as stiff as a piece of oak of the same dimensions and bearing.

159. Permanent alteration of structure takes place when a certain degree of strain continues for above a certain time, and as this alteration is a partial fracture, or at least failure of the material, it is of the greatest importance that the strain should never be more than that producing such alteration, and in timber, this appears to be about one-fifth of the cohesive force.

160. A hard body is that which yields least to any stroke or impressive force, and it may be shown, by the principles of mechanics, that in uniform bodies the degree of yielding is always proportional to the weight of the modulus of elasticity; therefore a table containing the weights of the modulus of elasticity of such bodies shows also their relative hardness and stiffness.

As the hardness follows the same laws as the stiffness, cast-iron is 10·6 times as hard as oak. But it is necessary to inform the student that when the substance is not uniform, the hardness thus found is that of the hardest part. Thus in fir, it is the darker part of the annual ring that is the hardest, and which determines the extent to which a beam will bend without fracture. Dry wood is harder than green, consequently it is more difficult to work. The labour of sawing dry Teak is to that of sawing green as 4 is to 3 nearly.

161. In respect to the toughness of woods, that wood is the toughest which combines the greatest degree of strength and flexibility; hence that wood which bears the greatest load, and bends the most at the time of fracture, is the toughest.

162. The opposite to hardness is softness, the opposite to toughness is brittleness, and the opposite to stiffness is flexibility; therefore when the hardness, toughness, or stiffness, of a wood is expressed by a low number, it may be considered to have the opposite quality.

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[*] Tredgold in his rules for the stiffness of timber employs constant numbers deduced from experiments, one of the elements of which is the "modulus of elasticity."—*Prin. Carpentry*, Art. 369.

DESCRIPTION OF WOODS.

SAUL *(Shorea Robusta).*

163. The tree from which this useful timber is obtained is found growing in extensive forests to the Northward of the Ganges lines, between the 25th and 31st degrees of North latitude, and 77° and 88° of East longitude.

That procured from the tract lying North of Purneah and Gorruckpore, is incomparably superior in every respect to the Saul of the forests Northward of Bareilly, with which the markets of the N. W. Provinces are chiefly supplied.

The Saul seems to thrive best in a rather dry soil and in uneven ground, rising into what may be termed low hills. That found growing on a slate-coloured loam, is always superior to the produce of the yellowish sandy loam; both of which soils this tree much affects, and on which it thrives equally well.

164. The height of this tree depends on local circumstances. In a dense forest and in favorable soil, it commonly attains a height of sixty feet to the lower branches, while in more open situations its height varies between thirty and fifty; in centre girth, the largest timbers measure from seven to eight feet.

From much observation it would appear that the Saul reaches maturity in about forty years, at which period it has usually attained a mean girth of six feet. At the age of thirty years, it has attained a mean girth of five feet, and at fifty years, a girth of seven feet.

Nothing is gained by allowing the tree to stand after it has reached maturity. It certainly continues to increase in girth for a longer or shorter period, but its prime is passed, or as it is technically termed, it is "on the return."

165. On ripping up a saul log whose centre girth is as much as seven feet, it will almost invariably be found, that decay has taken place at the pith or core, extending from crown to butt. In fact, it is the most central roots, which issue from the under surface of the "collet," or trunk, that are the first to decay, and these dying, leave the parts to which they belonged exposed to the damps of the soil.

It is found that after all the care that is bestowed on them, the larger scantlings of saul suffer greatly in the process of seasoning, from deep splits and cracks.

166. The sap is very volatile, and evaporates quickly on exposure to the air from the outer surfaces. But this drying is merely superficial, the interior of the piece retaining all its moisture, which on the first accession of a high temperature, causes the internal wood to expand and burst its outer shell, occasioning deep cracks and "faults."

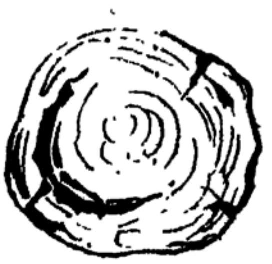
Small scantlings of saul suffer little injury in seasoning, as they give out the greater portion of their moisture at once and the shrinkage is thus equal throughout.

167. Saul is generally straight grained, and free from knots. It is strong and elastic when properly seasoned, and well adapted for a variety of purposes, especially for building.

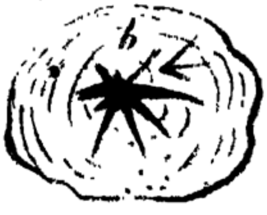
It has been shown above that the saul reaches maturity about the period when the mean centre girth of its trunk is six feet. If much material and large scantlings are required, choose timber of this size in preference to all others, as they will afford more stuff, and of a superior quality.

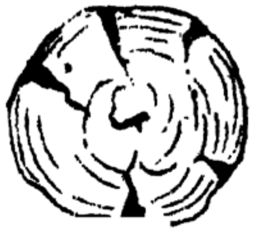
168. In selecting saul logs, choose those whose exterior surface is smooth and comely. They should be straight and free from knots caused by removed or decayed branches.

Examine the section at the ends. If there is any appearance of this sort reject the log at once, it will not pay for sawing up. This serious defect is called by the natives a "golah." It is caused by the separation of two contiguous annual layers, and is fatal to produce.



Sections of the crown and butt having these appearances should likewise be avoided. It is a very common custom of the dealers to tamp the hole at *b* caused by the decay of the pith, with a plug, and this they sometimes do so ingeniously as to escape detection when the log is dry, but if seen shortly after the log is taken from the raft, the oozing out of water proclaims the cheat.





169. The timbers of the North-West Provinces are brought to market in their natural shape, with merely the bark removed, but in the Bengal provinces, they are classed as "chowkers and "dhowkers," the former being squared on four, and the latter on two sides. The chowkers are the largest logs.

Sissoo, *(Dalbergia Sissoo).*

170. This useful and valuable wood is produced nearly throughout the Upper Provinces of India, but the best is procured from the forests beyond the Gograh River, in the territory of the King of Oude, and in Central India near the Nerbudda River.

The Sissoo will thrive on almost any kind of soil. Those on dry sandy soils have the quickest growth, but such usually throw out a luxuriant crop of branches, while the trunks are short and stunted, and soon become decayed at the pith. In such trees also the sap-wood is always more than proportionally abundant.

A moist clayey soil produces the best Sissoos, especially where, as in a dense forest, they are hampered by their close vicinity to each other, for the more encumbered they are by such proximity, and sheltered by the growth of other jungle, the better will they be found. In such situations the Sissoo will attain a great height, as much as 60 feet to the lower branches, with a centre girth of six feet. But this height varies from 15 feet upwards, according to local circumstances.

The forest Sissoo attains the thickness of five feet centre girth in about 35 years, and a girth of six feet in about 45 years. It is at maturity about midway between these two ages. Though in dry soils such as that of the Dooab, and in other parts of the open country it would reach this period 10 years earlier.

171. The best season for felling Sissoo, is from the latter end of October to the end of January. The logs are barked, and the after process of seasoning is carried out precisely as described under the article "Saul."

Sissoo is a kindly wood to season as it dries with comparatively few splits and cracks. During this process it loses about $\frac{1}{4}$th of its weight, and $\frac{1}{40}$th of its breadth and thickness.

172. The wood when green has a specific gravity of about 1·000. When seasoned of about 0·750.

173. The strength of a straight grained bar of Sissoo, free from knots, is equal to that of a similar bar of Bencowley Saul, but Sissoo is not generally straight grained, and is liable to hidden knots, nevertheless it is a very useful description of wood, and invaluable for many important purposes. Nothing can equal it in this country, for naves and felloes of wheels, and in the Ordnance Carriage Department its uses are manifold. Sissoo is excellent for every description of joiner's work,—it is very hard, durable, and takes a good polish. The graining of this wood is frequently very beautiful. It is besides very little affected by atmospheric changes

TEAK. *(Tectona Grandis.)*

174. Teak is a native of the mountainous parts of the Malabar and Coromandel Coasts, as well as of Java, Ceylon, the Tenasserim Provinces and other parts of the East Indies.

The Teak tree is of rapid growth and the trunk grows erect to a vast height, with copious spreading branches.

The wood of the Teak tree is by far the most useful timber in India; it is light, easily worked, and though porous, it is strong and durable; it requires little seasoning, and shrinks very little: it affords tar of good quality and is rather of an oily nature, therefore does not injure iron; and is the best wood for ship-timber, house-carpentry, or any other work, where strong and durable wood is required.

Malabar Teak is esteemed superior to any other in India, and is extensively used for ship-building at Bombay. It grows in the Teak forests, along the western side of the ghaut mountains and the contiguous ridges, where the numerous streams afford water-carriage for the timber.

175. The cohesive force of Teak wood varies from 13,000 to 15,000 pounds per square inch; the weight of its modulus of elasticity is 2,167,000 pounds per square inch, according to Mr. Barlow's experiments; and the weight of a cubic foot seasoned; varies from 41 to 53 pounds.

176. Representing the strength of Oak by 100, that of Teak will be 109
Stiffness of Oak by 100, ... 126
Toughness of Oak by 100, ... 94

From which it appears, that it is much superior to Oak in these properties except in toughness, but it is to be remembered that these proportions are drawn from two or three experiments on Teak, and most probably these were tried on very select specimens; whereas those for Oak are from a mean specimen, selected from pieces of Oak of various qualities.

177. Specific gravity dry, ... ·660
Ditto ditto fresh, ... ·820

TOON.

178. Very nearly resembles a dull coloured specimen of Mahogany, and would be useful for any purpose to which such kind of Mahogany is applicable; besides having a greater degree of strength and stiffness compared with its weight.

179. The cohesive force of Toon is from 10,000 to 14,700 lbs. per square inch; the mean weight of the modulus of elasticity for a base of an inch square is 1,689,800 lbs.

180. The specific gravity, and the relative strength, stiffness, and resilient power compared with Riga fir, as 1,000, from Mr. Barlow's experiments are as under—

Specific gravity.	Strength.	Stiffness.	Resilience.	
·579	1380	1270	1400	Barlow.

181. The above are the principal woods in use for building purposes in India, but there are many other valuable woods in the forests of Bundlecund, and the Saugor and Nerbudda Territories, which, by research and energy, might be brought into operation, such are—

182. Mowa, from Bundlecund, reckoned next to Saul, used by the Natives for beams, door-frames and other purposes, procurable in lengths of 16 to 18 feet and scantling 14′ × 12″.

Babool.—A valuable wood from its toughness, and applicable to various engineering purposes, such as wheels, trenails, &c.

Kheir or Khyre.—Similar in nature, texture and properties, and even better than Babool, found in Bundlecund abundantly.

Pursudh.—Indian Rose wood, a very fine, hard and extremely heavy wood found in the Saugor territories, partakes of all the qualities of Sissoo.

Beeja Saul, Khoura, from Bundlecund, and the Iron wood, Tilsur and Jarool from Arracan.

Their qualities might be tested in the same way as have been those of Saul and Teak, and their relative values registered.

OF THE EQUILIBRIUM AND PRESSURE OF BEAMS, OR THE STABILITY OF POSITION.

183. It is through a knowledge of the composition and resolution of forces alone that the carpenter can expect to arrive at excellence in the art of designing frames of timber, for the purposes of building, for machines and other uses; as without this knowledge, it would be impossible for him to understand clearly what is to be aimed at in such designs, or even to know whether a design of his own would answer its intended purpose or not.

184. The first step towards obtaining this knowledge, is that of acquiring just notions of the action of forces.

A heavy body always exerts a force equal to its own weight, in a vertical direction, and would always descend in a vertical line, if not prevented from following that direction by some other force, and its force is always the same as if it were collected in, and acting in, that line.

But when a heavy body *W* (plate 5, figure 3) is sustained by two beams, *A C* and *B C*, its effects on these beams depend on their position; the further the ends *A* and *B* are set apart, the greater will be the strains on the beams, and the contrary. Here it is obvious that the weight resolves itself into two forces, one in the direction of each beam.

185. We may now proceed to explain what is meant by the Composition and Resolution of forces.

The resolution of forces consists in finding two or more forces, which, acting in any different directions, shall balance or have the same effect as any given single force. Thus the weight *W* (figure 3) might be sustained by a vertical force in the direction *C c* equal to the weight; and this vertical force, it is obvious, may be resolved into two forces in the directions of the beams, that would produce exactly the same effect as the vertical force *C c*.

186. The composition of forces consists in finding one force that shall produce the same effect as two or more forces acting in different directions. This is nothing more than the reverse of the resolution of forces, and may be accomplished in a similar manner.

If a vertical line *C c* (figure 3) be drawn through the centre of the weight, and *a c* be drawn parallel to the beam *A C*, also *b c* parallel to *B C*; then the relations between the weight and the pressures will be found by the following proportions:—

As the line *C c*
Is to the line *C b*
So is the weight *W*.
To the pressure in the direction of the beam *A C*.
Also, as the line *C c*
Is to the line *C a*
So is the weight *W*
To the pressure in the direction of the beam *C B*.

To those who are acquainted with the principles of mechanics, the truth of the principle from which these proportions are derived, requires no illustration; but such as have not had the advantage of that branch of learning, may, by having recourse to the following simple experiment, not only satisfy themselves of its truth, but also render themselves more familiar with the nature of forces.

187. Let a thread or fine line be passed over the pulleys *B* and *C* (figure 4) and let a known weight be attached to each end of the line, as at *b* and *c*; also let another thread be knotted to the first one at any point *A*, and attach a

known weight to the end *W*. Then if the sum of the weights *b* and *c* be greater than the single weight *W*, there is a certain position in which the assemblage will be at rest; and if it be deranged by pulling at any of the weights, it will return of itself to the same position when left at liberty. Therefore in that position, and in that position only, the weights will balance one another, or be in equilibrio. Now if the positions of the threads, when the weights balance each other, were drawn upon paper, and from a scale of equal parts, *A F* were made equal to the number of pounds in the weight *W*, and the line *B A* were continued to *E*, and the line *F E* drawn parallel to *A C*, then *F E* measured by the same scale of equal parts would show the number of pounds' weights of the body *c*; also the measure of the line *A E* would be equal to the number of pounds' weight in the body *b*.

If the three weights be equal, then the three lines *A F*, *F E* and *A E* will be equal, and the angles formed by the threads round the knot will be equal.

And universally, whenever the directions of three forces are in the same plane, and meet in a point, and are in equilibrio, those forces will be represented in magnitude by the three sides of a triangle drawn parallel to the directions of the forces.

Consequently if a body be kept at rest by the forces, and any two of them be represented in magnitude and direction by two sides of a triangle, the third side taken in order will represent the magnitude and direction of the other force.

188. Also, because the sides of triangles are as the sines of the opposite angles, it follows, that when three forces keep a body in equilibrio, each force is proportional to the sine of the angle made by the directions of the other two. Thus the weight *W* (figure 4) is to the weight *b*, as the sine of the angle *A F E*, *&c.*

It may however be observed, that the designs of framing are drawn on paper to a scale; hence the proportions of the forces may always be obtained immediately from the figure without the trouble of calculation, and the values of the forces so obtained, will be accurate enough for any practical purpose.

189. Again considering the combination of forces in (figure 3), let the vertical line *C c* be drawn, and by a scale of equal parts make *C c* equal to the number of pounds, hundred-weights, or tons contained in the weight *W*. Then draw *c b* parallel to *B C* and *c a* parallel to *A C*, and *C b*, measured from the

same scale, will show the number of pounds, hundred-weights, or tons, by which the beam *C A* is strained; and, in like manner, *C a* will be the measure of the strain on the beam *C B* in pounds, hundred-weights, or tons. The pressure is not altered by making the beams longer or shorter, so long as their positions remain the same; but the power of a beam to resist pressure is much lessened by increasing its length.

OF THE EFFECT OF POSITION.

190. If the position of the beam *C B* (figure 3) were changed to that shown by the dotted lines *C E*, the magnitude of the strain would be prodigiously increased on both beams. By drawing lines parallel to the beams in this position, expressing the weight by the line *C c* the same as before, the pressure on the beam in the position *C E* will now be measured by the line *C d* instead of *C a*, being obviously much increased; while the strain on the beam *C A* will be nearly doubled, being represented by the line *C e*.

Hence it appears that enormous strains may be produced by a comparatively small weight, merely by altering the position of the supports. The student will do well to consider these changes with attention, and to draw figures in different positions, estimating the pressures according to each position, which will render his mind familiar with the subject, and enable him in practice, to form accurate notions of the magnitudes of pressures, without the labour of calculation.

TO MEASURE THE STRAINS IN A FRAMED TRUSS.

191. If, instead of placing the weight on the point where the beams meet, the beams were framed into a piece of timber, *C E* (figure 5,) and the weight *W* suspended at *E*, the pressures would still be propagated in the same manner and would be found by the same means; that is, if *C c* represent the weight, *C b.* will be the pressure in the direction of the beam *C A*, and *C a* the pressure in the direction of the beam *C B*.

In this case *C E* performs the office of the king-post in a roof.

192. Hitherto the ends of the beams, marked *A* and *B* in (figures 3 and 5) have been considered to be supported by an immoveable obstacle, but when

there are no such obstacles, they obviously have a tendency to spread, therefore they might be connected by a rope, a rod of iron, or another beam, which would answer a purpose nearly similar to the tie-beam of a roof.

Let (figure 6) represent an assemblage of this kind, where *A B* is the tie to prevent the lower ends of the beams *A C* and *C B* from spreading. This form is similar to the truss of a roof.

The strain on the tie *A B* may be found by drawing *b f* parallel to the tie *A B*, then, if *C b* represent the pounds or tons with which *A C* is pressed, *b f* measured from the same scale of equal parts, will be equal to the strain in the direction of the length of the beam or tie *A B* in pounds or tons: and the equal and opposite strain at *B* will be measured by *e a*.

If the load, and therefore the king-post, be in the middle of the span, the pressures on the walls will be equal; but when out of the middle the pressures will be unequal, and the point *f* divides the line *C c* into two parts which are proportional to the pressures; *C f* being the pressure on the wall at *A*, and *f c* or *C e* the pressure on it at *B*, when *C c* is the whole weight.

OF FRAMED LEVERS.

193. Let (figure 6, plate 5) be inverted, and supported at *C*, as represented in (figure 7,) and a weight hung at each end, so as to balance one another; then the proportion of the strains would remain precisely the same: and it shows how a powerful lever may be framed, and also makes us acquainted with the nature of the strains produced in a solid beam, when it performs the office of a lever. The tie *A B* is in a state of tension, the beams *A C* and *B C* are compressed: in a solid beam the same thing takes place; the side next the support is always compressed, and the opposite side is always in a state of tension.

TO DISTINGUISH TIES FROM STRUTS.

194. It is necessary, in designing the construction, as well as in estimating the strength of framing, that we should be able to distinguish the struts

from the ties; that is, to ascertain which of the beams are compressed, and which of them are stretched; for ties must be either continuous or connected by straps, but struts may be in short lengths. By attending to the following considerations, this may be easily determined.

195. Let a parallelogram be constructed on the direction of the straining force as a diagonal, the sides of the parallelogram being parallel to the sustaining forces; then let the other diagonal of the parallelogram be drawn, and parallel to it draw a line through the point where the directions of the forces meet. Consider towards which side of this line the straining force would move if left at liberty, and all supports on that side will be in a state of compression, and all those on the other side will be in a state of tension.

196. The same thing would be true of a plane passing through the point where the forces meet, when three or more forces meet that are not in the same plane, but such cases are of rare occurrence; therefore, I shall only consider the examples in (figures 5 and 8, plate 5,) which will enable the student to apply the method to all cases where the sustaining forces are in the same plane.

In (figures 5 and 8, Plate 5,) *C c* is the direction of the straining force, on which as a diagonal the parallelogram *C b c a* is drawn, the sides of it being parallel to the resisting or sustaining beams: join *b a* and draw the dotted line *e é* parallel to *b a* in each figure; then, in (figure 5,) the straining force would move towards *E*, if left at liberty; therefore both the beams are compressed, being both on that side of the line *e é*.

In (figure 8,) only the lower sustaining beams are compressed; the upper ones are extended.

TO FIND THE RESULTANT OF A SYSTEM OF FORCES.

197. As the strain upon a piece of framing is often produced by two or more forces, acting in different directions, of which the crane is an instance, the means of finding a force and its direction that would be equal in effect to two or more forces may be next considered a little more attentively. In all cases where the strain is produced by the action of several forces meeting in one point, these forces must be reduced to a single force, capable of producing

the same effect; otherwise it will not be possible to determine the strain upon the supports.

A force capable of producing the same effect as two or more forces is called the resultant of those forces.

198. Let *A C* represent the magnitude and direction of a force, acting on the body *C* (plate 5, figure 9,) and *B C* the magnitude and direction of another force also acting on the body *C*. Then to find the resultant, draw *b B* parallel to *A C*, and *A b* parallel to *B C;* join *b C* which represents the resultant required. The lines connecting the points *A C B b* form a parallelogram, of which *b C* is the diagonal; and whenever two sides of a parallelogram are parallel to the directions, and proportional to the energies of two forces, the diagonal will represent the direction and energy of a force that would produce the same effect. A parallelogram constructed in this manner is called a parallelogram of forces.

199. Also if the force *b C* were to act in the opposite direction. that is, from *a* towards *C* it would retain the two forces *A C*, and *B C* in equilibrio; these acting from *A* and *B* towards *C*; but two forces only can never be in equilibrium unless their directions be exactly opposite, and the forces equal; and the direction they would move in when not exactly opposite, is shown by producing the diagonal of the parallelogram drawn on their directions. Thus *C a* (figure 9, plate 5,) is the diagonal produced, and consequently the direction in which the forces *A C* and *B C* would cause the body *C* to move.

One of these forces may be the weight of a structure of which the direction is vertical, the other force the action of the wind upon it, which is horizontal; the resultant shows the direction and intensity of both the forces acting together.

OF THE CENTRE OF GRAVITY.

200. In a heavy beam there is a single point by which it may be supported, and if so supported, it may be placed in any position, and remain at rest. Whereas, were it supported by any other point, it would rest only in certain positions.

This point is called the centre of gravity of the beam.

201. A beam *A B* suspended by a pin at *C* (figure 10, plate 5,) passing exactly through the centre of gravity, will rest in the position *A B*, or in that shown by the dotted lines *a b*, or any other. And the same thing will take place, let the body be ever so irregular provided the support passes exactly through the centre of gravity.

The centre of gravity of a uniform cylinder or prism, is in its axis and at the middle of its length.

In a triangle the centre of gravity is in a line drawn from the vertex to the middle of the base, and at a distance of one-third of that line from the base.

In cones or pyramids the centre of gravity is in the axis and one-fourth of the height from the base.

The most useful mechanical methods of finding the centre of gravity are the following:

202. To find the centre of gravity of a body with plain sides, suspend it by the cord *A E B* (figure 11,) fixed to the body at *A* and *B*, and passing over a pin *E*. When the body is at rest, by means of a line and plummet, draw a plumb or vertical line upon it, as at *a b*. Then slide the cord upon the pin *E*, so as to change the position of the body as much as possible; and when it is at rest again, draw another vertical line upon it, and where this vertical line crosses the former one will be the centre of gravity of the body.

OF THE PRESSURE OF INCLINED BEAMS.

203. Let *A B* be a beam (plate 5, figure 12,) resting against the vertical wall *B D*, and C its centre of gravity; the lower end resting on an abutment cut in the beam *A D*. Through the centre of gravity C draw the vertical line *c e* and draw *c B* perpendicular to *B D* meeting *c e* in *c*, join *A c* which will be the direction of the pressure against the abutment at *A*, and that the beam may have no tendency whatever to slide, the abutment should be perpendicular to *A c*.

Also, if *c e* taken from a scale of equal parts, represent the weight, and *a e* be drawn parallel to *c B* then *a e* will represent the pressure against the wall at *B* and *c a* the pressure against the abutment at *A*. The horizontal thrust at the abutment *A* is also measured by the line *a e* as it is always equal to the horizontal pressure against the wall at *B*. The pressures of sheds or lean-to roofing are shown by this example.

204. When the centre of gravity is at the middle of the length of the rafter or beam, multiply the weight in pounds by the distance *A E* in feet, (which in a roof is half the span), and divide the product by twice the height *D E* in feet, and the quotient will be the horizontal thrust. (Figure 13.)

Example.—The weight uniformly distributed over a rafter is 200 pounds; the span of the roof is 20 feet, half of which is 10 feet; and the height of the roof is five feet.

Then $\frac{200 \times 10}{2 \times 5} = 200$ pounds, the horizontal thrust, which is the same as the weight, and will always be so when the roof rises exactly one-fourth of the span, but not in other cases.

OF THE STRAIN UPON BEAMS LAID HORIZONTAL.

205. When a beam is laid in a horizontal position, as in (figure 14,) and a load is uniformly distributed over its length, or the beam is only loaded by its own weight, the strain upon the beam is the same as if half the weight were acting at its centre of gravity.

But if the weight be distributed over the beam, it must be of a yielding nature, otherwise this rule will not hold good. If a strong short beam be laid upon the first beam, and the weight upon that, the strain upon the lower beam would be removed to the points where the ends of the short beam would rest upon the longer one, and of course the strength of the longer one would be much increased.

206. When a beam is supported at the ends, as (figure 15,) the stress arising from any weight *W* produces the greatest strain when it is applied in the middle of the length. And, if *w* be the greatest weight the beam would support in the middle, the greatest weight *W* that it could support at any other point *C* will be found by the following proportion:

As the distance *A C* multiplied by the distance *B C*,
Is to the square of half the length of the beam;
So is the weight *w*, that could be supported in the middle,—
To the weight *W* that could be supported at the point *C*.*

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* Tredgold.

GENERAL OBSERVATIONS ON DESIGNING, FRAMING, &c.

207. The principal questions relative to the action of forces on single beams, and on systems of framing, have now been considered; and it only remains to make a few remarks on the best method of applying those principles so as to form a perfect design.

In the first place the artist must remember "that the strength of a piece of framing, whatever may be the design, can never exceed that of its weakest parts; and that partial strength produces general weakness.'

Therefore, let the fixed conditions, or those objects which cannot be altered, be well considered; and as far as it can be done, let them be drawn correctly to a scale; showing the curves of equilibrium, the points where the forces act, and every other particular condition. Also, it must be considered whether the forces are to act constantly on the same parts, or to be subject to changes; and the nature and extent of these changes should be exhibited.

Secondly.—The nature of the sustaining points should be carefully examined, whether they be capable of resisting a force acting obliquely against them or not; and the framing must be disposed accordingly.

Then a design may be sketched in of such a nature as shall appear best adapted to attain the objects in view, taking care to avoid transverse strains as much as possible, to load obtuse angles lightly, and to give little excess of strength to parts which themselves add to the load to be supported; the proper degree of strength may be fixed by the rules which follow:

Nothing will assist the artist more in forming a good design, than just conceptions of the objects to be attained; and nothing will render those objects more familiar to the mind, than drawing them.

OF THE RESISTANCE OF TIMBER, OR THE STABILITY OF RESISTANCE.

208. To know the resistance which a piece of timber offers to any force tending to change its form, is one of the most important species of knowledge

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[*] Seppings' Philosophical Transactions.

that a carpenter has to acquire; and to be able to judge of this degree of resistance from observation only, even in common cases, requires nothing less than the practice of a life devoted wholly to carpentry.

Besides, it is a species of knowledge that is confined to the person who has obtained it and it dies with him. It is a feeling of fitness which can neither be communicated nor described; nevertheless it is a feeling that every thinking practical man is sensible he possesses. There are many besides practical carpenters, who ought to know something of the principles of building, and who have not an opportunity of becoming acquainted with those principles through practice; to such persons the rules and experiments herein detailed, will be found extremely useful.

209. In order to be able to determine the dimensions or scantling of a piece of timber, which shall be capable of sustaining a given weight or pressure, the laws that regulate its resistance should be considered; and to accomplish this in a manner likely to be useful, we must consider what effect is produced when a piece of timber is overloaded. This effect, in general, is nothing more than a certain degree of flexure, or bending, as it seldom happens that timbers are absolutely broken; and generally, a small degree of bending renders a beam unfit for its intended purpose.

DEFINITIONS AND GENERAL PRINCIPLES.

210. The laws of the resistance of materials depend on the manner in which the pieces are strained, and may be divided into three kinds:

First.—When the force tends to pull the piece asunder in the direction of its length, or the resistance to tension.

Secondly.—When the force tends to break the piece across, or the resistance to cross strains.

Thirdly.—When the force tends to compress the body in the direction of its length, or the resistance to compression.

211. "*Stiffness*" is that property of bodies by which they resist flexure or bending; "*Strength*" is that by which they resist fracture or breaking. This distinction must be carefully attended to, because the laws of strength and stiffness are not the same. For instance, the stiffness of a cylinder, exposed

to a cross strain, increases as the fourth power of the diameter, but the strength increases only as the cube of the diameter. If the diameter of a cylinder be doubled, its stiffness will be sixteen times as great, but its strength will only be increased eight times.

OF THE STIFFNESS OF BEAMS TO RESIST CROSS STRAINS.

212. When a weight is laid upon the middle of a piece of timber which is supported only at the ends, it always bends more or less; when the weight bends the piece in a very small degree, the wood is said to be stiff; when the the bending is considerable, it is called flexible.

The stiffness of beams is proportional to the space they are bent through by a given weight, when the lengths are the same, but that two pieces of different lengths may be equally stiff, the deflexion or bending, should be proportional to their lengths. For a deflexion of one-fourth of an inch in a joist 20 feet long would not be attended with any bad effect; but if a joist 4 feet long were to bend one-fourth of an inch, it would be totally unfit for its purpose.

ON THE TRANSVERSE STRENGTH OF BEAMS.

213. The transverse strength of rectangular beams, or the resistance which they offer to fracture, is as the breadth and square of the depth: therefore, if two rectangular beams have the same depth, their strengths are to each other as their breadths; but if their breadths are the same, then their strengths are to each other as the squares of their depths.

214. The transverse strengths of square beams are as the cubes of the breadths or depths. Also in cylindrical beams, the transverse strengths are as the cubes of the diameters.

Thus, if a beam which is one foot broad and one foot deep support a given weight, then a beam of the same depth and two feet broad will support double the weight.

But if a beam be one foot broad and two feet deep, it will support four times as much as a beam one foot broad and one foot deep.

If a beam one foot square support a given weight, then a beam two feet square will support eight times as much. Also a cylinder of two inches in diameter will support eight times as much as a cylinder one inch in diameter.

215. In the following table the value of the transverse strength of teak is computed from the formula by Barlow* $S = \frac{l\,W}{4\,a\,d^2}$ and from various experiments which were carefully conducted at Cossipore, in 1826, the values of other woods are added from the same formula.

TABLE OF DATA.

Teak,	2462	(Barlow).
Rangoon Teak, (seasoned),	2046	Cosssipore Expt.
Bombay Teak, (ditto),	1548	ditto.
Bengal Soondry, (ditto),	2595	ditto.
Morung Saul Choukers, (ditto),	2473	ditto.
Ditto, (unseasoned),	2053	ditto.
Morung Saul Dhoukers, (seasoned),	2298	ditto
Ditto, (unseasoned),	2452	ditto.
Goruckpore Saul, (not seasoned),	2212	ditto.
Bengal Deal,	1329	ditto.
Morung Toon,	1269	ditto.
Norway Deal,	1083	ditto.
American Ash,	906	ditto.
Morung Sissoo, (seasoned),	2308	ditto.

216. To find the ultimate transverse strength of any rectangular beam of timber, fixed at one end and loaded at the other.

RULE.—Multiply the value given in the table of data by the breadth and square of the depth, both in inches, and divide that product by the length, also in inches, and the quotient will be the weight in pounds.

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* Essay on strength of timber, p. 161, where a is the breadth, d the depth, l the length, w the breaking weight in lbs., S the resistance of a rod an inch square.

Example.—What weight will it require to break a beam of Teak, the breadth of which is 6 inches, the depth 8 inches, and length 20 feet?

In the table of data the value of Teak is 2462.

Then by Rule $\frac{2462 \times 6 \times 8^2}{240} = 3939$ lbs.

217. Or, if the dimensions of a beam be required, so as to support a given weight at its end, then—

Multiply the weight in pounds by the length in inches; and this product, divided by the tabular value, will give the product of the breadth and square of the depth.

Example.—A square balk of Saul projects 4 feet 6 inches from a solid wall in which it is fixed; what must be the side of its square, so that it may support 1013 lbs.?

Tabular value of Saul is 2473.

$\frac{54 \times 1013}{2473} = \frac{54.702}{2,473} = 22{\cdot}12$, the cube root of which is 2·8 inches, the side of the square required.

218. To determine the strength of a rectangular beam of timber, when it is supported at the ends, and is loaded in the middle of its length.

Rule.—Multiply the value in the table of data, by 4 times the depth in inches, and by the area of the Section in inches, and divide the product by the distance between the supports in inches, and the quotient will be the greatest weight the beam will bear in lbs.

Note 1.—If the beam be not horizontal, the distance between the supports must be the horizontal distance.

Note 2.—One-fourth of the weight found by the Rule should be the greatest weight upon a beam in practice.

Note 3.—If the load be applied at any other point than the middle, it will be as the rectangle of the segments, into which the point divides the distance between the supports, is to the square of half that distance; so is the weight found by the Rule, to the weight the beam will sustain at the given point.

Note 4.—If the load be distributed in any manner whatever over the beam, the centre of gravity of the load must be considered its place, and its stress equal to the whole weight, unless part of the supporting points independently of the resistan

219. Example.—Required the weight a be middle 12 inches deep and 8 inches wide, the length

Tabular value of Saul is 2473, depth 12 in length 240 inches.

$$\frac{2473 \times 4 \times 12 \times 96}{240} = 47,481$$

and the beam may be loaded in practice with $\frac{47,481}{.} = 11.870$ lbs. without injury to texture.

220. When a long beam *A B* is laid over several points of support, as in (figure 17, plate 5), a case of very common occurrence in building, the strength of the intermediate parts is nearly doubled, or twice as much as when the beams are cut into short lengths. Hence the carpenter will see the importance of using bridging and ceiling joists, purlins and rafters, in considerable lengths, so that a joist may extend over several binding joists, purlins over several trusses, and a rafter over several purlins: also, by contriving so that the joinings shall not be opposite one another, a floor or roof may be made tolerably equal in strength. Hence also, we see the importance of notching joists, purlins, and rafters over the supports, instead of framing them between.

ON THE RESISTANCE TO COMPRESSION.

221. When a piece of timber is compressed in the direction of its length, it yields to the force in a different manner, according to the proportion between its length and the area of its cross section. For more convenient illustration, let us suppose the piece to be a cylinder; then, if its length be greater than about eight times its diameter, the force will cause it to bend in the manner shown in (figure 16, plate 5), and it will break at the middle of its length. But when the length of a wooden cylinder is less than about eight times its diameter, the piece will expand in the middle of its length, and split in several places. Materials less flexible than timber, break in different ways when under compression in short lengths.

The case where the length exceeds about eight times the diameter is that which is most useful.

ON THE STRENGTH OF COLUMNS AND POSTS TO RESIST FLEXURE.

222. It is known from experience, that there is a certain force, that will bend a piece of timber when acting in the direction of its length; and that when it has been bent in a small degree, a still greater force is required to complete the fracture. But our investigation must be confined to the strength to resist the first degrees of flexure.

The strain will be directly as the weight or pressure, and inversely as the strength which is inversely as the cube of the diameter. The strain will also be directly as the deflexion, which will be directly as the quantity of angular motion, and as the number of parts strained; that is, directly as the square of the length, and inversely as the diameter.

223. When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn sides outwards; the girders in the section, (figure 18), are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or fitches, should be thick enough to allow the air to circulate freely between them. It is generally imagined, that it strengthens a girder to cut it down, reverse it, and bolt it together again; it is in fact weakened by the operation, but the method is recommended here for the reasons above stated.

Others suppose that girders are cut down merely for the purpose of equalizing their stiffness; but admitting a girder to be bent considerably, the difference between the deflexions at any two points equally distant from the middle would not be sensible in girders of the usual form. The person who first practised the method of cutting girders down the middle undoubtedly did it with a view of preserving and not of stiffening them. We find, that

Vitruvius,* the oldest author on architecture whose works are extant, directs a space of two fingers' breadth to be left between the beams for forming the architrave over columns, in order that the air may circulate between and prevent decay. Every one must have observed, that decay begins in the first place at the joints, and other parts where the pieces are neither perfectly close nor yet sufficiently open to allow any dampness to evaporate.

The principles of carpentry will be treated of, in Part II., under the head of "Roofs."

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* Vitruvius, lib. iv. Cap. 7.

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